



# CHEMICAL ENGINEERING

December  
2024

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# COST ENGINEERING

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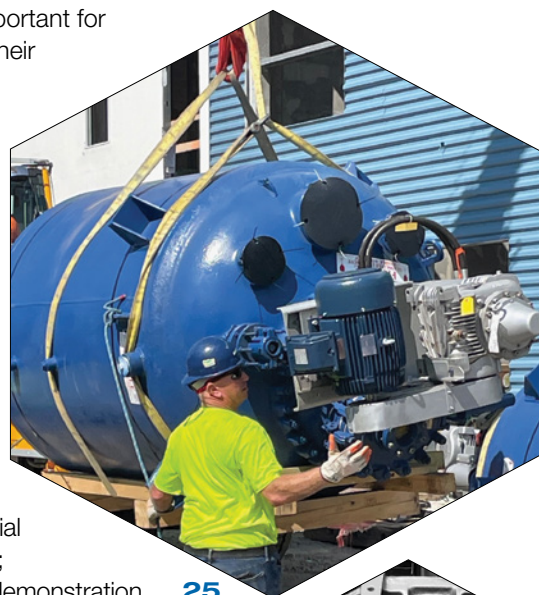
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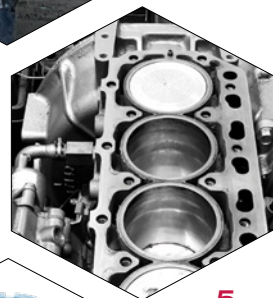
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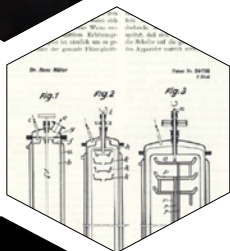
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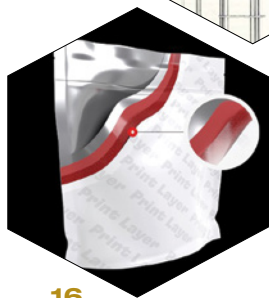
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## Electrochemistry and much more

A couple of years ago on *Chemical Engineering's* 120th anniversary, I looked back at the history of this publication and at that time, I wrote: "In September of 1902, the first issue of *Electrochemical Industry* was published to serve those applying the principles of electrochemistry in industry. Excerpts from that first issue indicate that growth in the electrochemical industry was largely aided by the growing availability of electric power, particularly from hydroelectric power such as at Niagara Falls. An article in that issue by professor C.F. Burgess states that 'Chemical manufacturing was a number of years ago considered best developed when the processes were so simple that no power was necessary to assist in the chemical reactions, but this condition has changed and the chemical industries are now pre-eminently power-using industries.'"

The name of the publication changed in 1905 to *Electrochemical and Metallurgical Industry*, and after a couple more name iterations eventually became *Chemical Engineering* in 1946.

This publication's root in electrochemistry was on my mind this month while editing the article "Electrochemical Processes for the Chemical Industry" (pp. 29–33). Changes in power generation, availability and costs affect the energy-intensive chemical process industries (CPI). With a sharpened focus on decarbonization and an "energy transition" moving toward electrification, interest in electrochemistry is resurging. The authors of the Feature Report give examples of modern electrochemical processes, and share their experience in scale-up.

## Also in this issue

As always, this month's *Chemical Engineering* covers a wide-breadth of topics. The field of chemical engineering itself is applicable to fields as broad as petroleum refining, mining, pharmaceuticals, bioengineering, agriculture, energy, food-and-beverages and many more. We typically refer to this broad group of industries as the CPI. With each issue we strive to fill these pages with articles that are broad enough to inform engineers throughout their many varied job functions, and yet detailed enough to be useful.

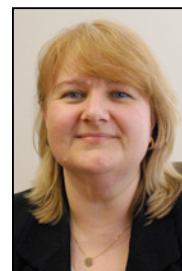
Early in my career I spent a good number of years as a process development engineer, working on scale-up and troubleshooting of new processes. While most of my education was focused on the scientific and technical aspects of chemical engineering, one of the things I learned early on in industry is that in addition to the technical challenges of process development, economics can make or break a project. Our two-part cover story on cost engineering (pp. 19–28) addresses cost estimating techniques and considerations in choosing new or used equipment.

Safety is always of utmost importance in the CPI, as our Environmental Manager article (pp. 34–36) notes, while discussing hazard reviews. This issue also features another installation of the "Tower Doctor," sharing distillation troubleshooting expertise; a Newsfront on level measurement; a Chem Chronicles on the history of thin-film evaporators and more.

This past month we also started something new — a short, editorial roundup podcast that highlights some of our content online and in print including articles, latest news and upcoming webinars. You can find it on our homepage at chemengonline.com if you'd like to listen in.

We wish all of our readers happy holidays and all the best as a new year approaches. We hope you enjoy reading, and listening.

Dorothy Lozowski, Editorial Director



## Upgrading organic wastewater into fuel feedstocks

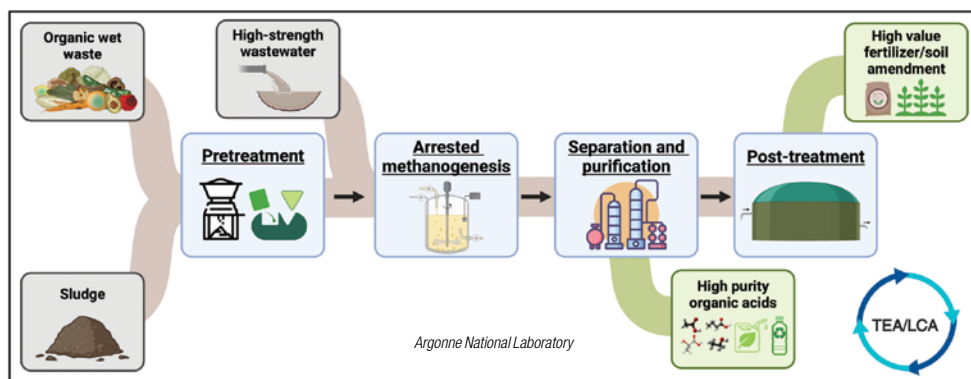
**A**lthough wastewater streams with high organic content — such as those from breweries and dairy facilities — can be difficult to treat and expensive to dispose of, there is potential to valorize their carbon content with the right process. Based on a technology called membrane-assisted methane-arrested anaerobic digestion (MAAD), a process developed at Argonne National Laboratory (ANL; Lemont, Ill.; [www.anl.gov](http://www.anl.gov)) can readily convert high-strength organic wastewater into volatile fatty acids like butyric acid, a low-carbon-intensity feedstock suitable for sustainable aviation fuel (SAF) production. According to ANL, the process (diagram) boasts a considerably lower carbon footprint than other SAF feedstocks, such as energy crops or lignocellulosic sugars. “When we look at the production of cheese or beer, they are already using a lot of water in the process, and their waste streams are very carbon-rich. Valorization of these organic waste streams provides us negative or very low carbon-intensity feedstocks for SAF. Conversely, with crops, we

need to look at the entire supply chain to understand what the carbon intensity of the feedstock will be,” says Meltem Urgun-Demirtas, department manager — Sustainable Materials and Processes at ANL.

The team from ANL developed a method to shut down the production of methane within the anaerobic digester, and use a

“highly diverse and highly dynamic microbial community structure” to focus only on short-chain fatty acids needed for SAF production. The next step was to tackle the separation and purification of the desired product from the reactor system. “Separation and purification can account for up to 70% of total production costs, so we integrated both production and separation/purification technologies together,” adds Urgun-Demirtas, noting that the team also developed a new electrochemical separation method to accompany MAAD. “By combining separation and purification with the production process, we have not only reduced the costs, but are also reducing the concentrations of the high organic acid in the bioreactor, which can inhibit microorganism activity. Thus, we are increasing overall productivity for the SAF feedstock,” she notes.

The team is currently working on proposals to pilot the technology in the field using wastewater from cheese or beer production. Currently, they have demonstrated the technology at the 100-gal scale.



## New injector technology fundamentally improves combustion flexibility

**C**onventional combustors that employ air-blast and pressure-swirl injection technologies are very sensitive to fuel properties, especially viscosity, limiting their ability to utilize certain classes of fuels and blends, including bio-based fuels. The new swirl-burst (SB) fuel-injector technology developed at Baylor University (Waco, Tex.; [www.baylor.edu](http://www.baylor.edu)) by mechanical engineering professor Lulin Jiang and her research team leverages an advanced atomization process that enables combustion of very viscous oils without any preheating. “The SB injector, with its unique geometry, generates internal two-phase flow to immediately create a fine fuel spray at the injector exit. Conversely, traditional injectors will first discharge a liquid jet core or film, which will very gradually disintegrate into ligaments, then large droplets and then, finally, finer droplets, even for conventional low-viscosity fuels,” explains Jiang. Easily creating fine spray is key when dealing with liquid fuels because larger droplets will result in pollutant emissions. For viscous liquids, such as glycerol, those conventional injectors lead to even coarser sprays that are difficult to ignite without further increasing emissions.

Additionally, at higher flowrates, other injection meth-

ods using two-phase flows may experience internal gas voids, which can cause pulsating fuel spray, paralyzing the flame stability. “With the new SB injector, the integrated swirls help to overcome that hindrance — even with higher flowrates, it does not generate gas voids internally. It also generates more uniform droplet-size distribution compared to other technologies, which can generate many large droplets or ligaments at the periphery, increasing emissions,” she adds. The team has tested the SB injector with many different fuel blends, covering a wide range of fuel properties, including glycerol, methanol, diesel, vegetable oil, SAF and even straight algae oil. “I believe we were the first team to directly burn algae oil without preheating the fuel or the air,” notes Jiang.

Now, in a project funded by the U.S. Dept. of Energy and the National Science Foundation, the technology is set to be deployed in a waste-to-energy process at a landfill near Waco. This pilot system will begin testing in early 2025 and will help to reduce methane emissions and other pollutants from the site, while producing resilient energy. Beyond combustion, the atomization technology of the SB injector could provide value in medical, agricultural and spray-coating applications.

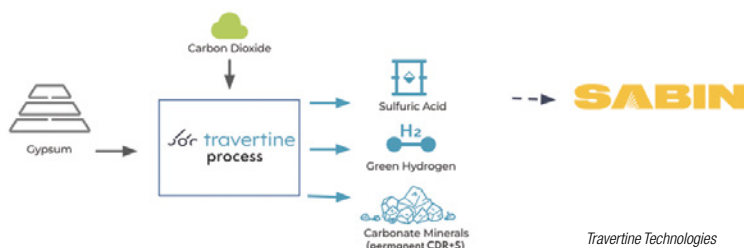
## Upcycling gypsum to sulfuric acid in a zero-liquid-discharge demonstration plant

A new demonstration plant is upcycling gypsum (calcium sulfate) — a material that is typically challenging to dispose of — at a metal-refining site using a process that combines salt-splitting electrolysis, caustic direct-air capture (DAC) and mineralization. Travertine Technologies, Inc. (Boulder, Colo.; [www.travertinetech.com](http://www.travertinetech.com)) will be deploying its namesake process technology at a facility owned by Sabin Metal Corp. (East Hampton, N.Y.; [www.sabinmetal.com](http://www.sabinmetal.com)), located near Rochester, N.Y. “The Travertine Process will be processing a legacy stack of mined gypsum at the site and carbon dioxide captured directly from the air into sulfuric acid, green hydrogen and calcium carbonate. The gypsum is from a historical gypsum mine that operated at the site prior to Sabin acquiring the land. Sabin will be using the sulfuric acid we produce for recycling and refining precious metals,” explains Owen Cadwalader, chief operating officer at Travertine. Besides sulfuric acid, the process also produces a stream of “green” hydrogen in the electrolysis step, which will be evaluated as potential fuel for the site. Finally, adds Cadwalader, the carbonate product acts as a permanent carbon sink that will be tested for use as a supplementary cementitious material.

At the heart of the process is the electrolyzer unit, which splits sulfate salt into sulfuric

acid and caustic (NaOH), and can be configured to also produce green hydrogen. “In the DAC unit, the caustic reacts with the CO<sub>2</sub> in air to produce sodium carbonate and CO<sub>2</sub>-depleted air. The carbonate solution flows into our mineralization unit operation and reacts with the waste gypsum, forming the sulfate salt, which is recycled to the electrolyzer, as well as precipitated calcium carbonate, which permanently sequesters CO<sub>2</sub>,” says Cadwalader, also noting that the plant is designed for zero-liquid discharge.

All equipment is similar to equipment that has been used at the industrial scale for decades: the electrolyzer unit operation is inspired by membrane chlor-alkali; the DAC unit resembles a cross-flow cooling tower; and the mineralization unit consists of hydrometallurgical equipment. The project with Sabin Metals will be the largest demonstration of the Travertine Process to date, with a nameplate capacity of 125 ton/d of sulfuric acid.



## Catalyst developed for conversion of CH<sub>4</sub> to methanol

Scientists at the Brookhaven National Laboratory (BNL; Upton, N.Y.; [www.bnl.gov](http://www.bnl.gov)) and collaborating institutions have engineered a highly selective catalyst that can convert methane into methanol in a one-step reaction. The system could help make better use of “stranded” natural gas reserves in remote areas by converting methane gas into a transportable liquid.

The researchers developed a palladium-based catalyst (photo) for the reaction based on years of basic research on the three-phase reaction of methane gas, hydrogen peroxide as an oxidant and solid-powder catalysts. Using the catalyst, the direct process for methane-to-methanol conversion runs at lower temperatures than traditional multistep conversions and produces methanol without additional byproducts, the BNL team says.

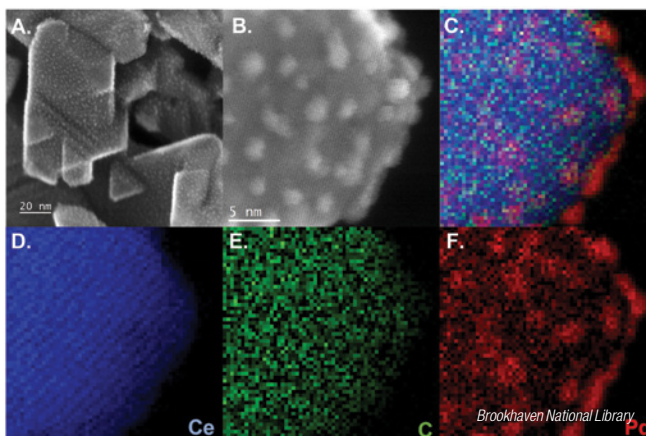
In addition, this new work “translates the laboratory-scale catalyst synthesis into a more practical process for making kilogram-scale amounts of catalytic powder,” explains BNL chemist Sanjaya Senanayake, co-author of a recent paper describing the work in the *Journal of the American Chemical Society*.

A key aspect of the catalyst seems to be a layer of carbon between the palladium and cerium oxide. The BNL synthesis method yields Pd-iC-CeO<sub>2</sub>, where iC refers to interfacial carbon. BNL chemical engineer and study lead author Juan Jimenez says “Carbon is often

overlooked as a catalyst, but in this study, we did a host of experiments and theoretical work that revealed that a fine layer of carbon between palladium and cerium oxide really drove the chemistry.”

Modulating the activity of highly active metal-oxide interfaces by the incorporation of carbon interlayers balances the activation of the oxidant in tandem with the CH<sub>4</sub> to achieve ideal product selectivity, the researchers say. This results in a methanol selectivity of 100% at 75°C, they add.

BNL is exploring collaborations with entrepreneurial partners to bring the technology to market.



## A more economical process for bio-succinic acid piloted

**B**io-based succinic acid has been explored as a renewable building-block for a host of chemicals and polymers, but its production process remains costly due largely to the complicated purification process that generates a large waste stream. Now, researchers at the University of Illinois Urbana-Champaign ([www.illinois.edu](http://www.illinois.edu)) led by bioengineer Huimin Zhao have piloted a process for streamlining the purification process and eliminating the waste stream generated in the current process. The approach could reduce the cost of producing bio-succinic acid significantly, placing it at a cost that is competitive with conventional chemical synthesis of succinic acid.

Previous attempts to make bio-based succinic acid have been expensive because the production organisms carrying out the fermentation cannot tolerate low-pH environments. “In existing bio-succinic acid production processes, the organisms can’t survive the acidic conditions generated as the succinic acid is produced, so researchers have to add a base to keep the pH neutral,” explains Zhao, “The addition of base generates a calcium sulfate (gypsum) side product that complicates the downstream purification and leaves the process with a large waste stream to address.”

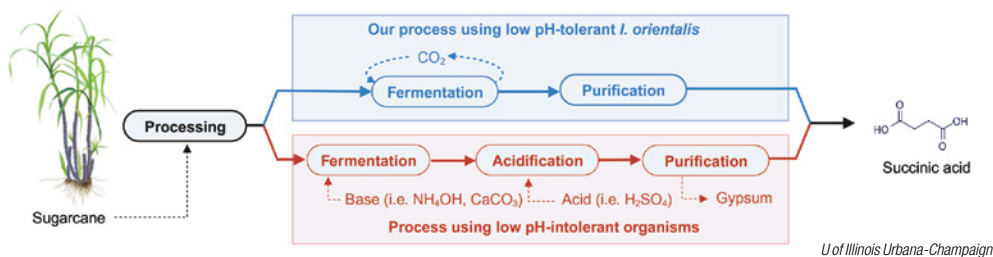
Zhao’s team started with a naturally occurring strain of yeast that is tolerant of low pH, and then genetically engineered its metabolic pathways so that it produces more than ten times the levels of succinic acid compared to the original yeast. “With acid-tolerating yeast in the fermentation process, you no longer have to add base, so you elim-

inate several purification steps and eliminate the need to handle calcium sulfate solutions,” Zhao says (diagram).

After a years-long process to develop genetic engineering tools for use in this organism, Zhao’s group was able to coax the yeast into producing succinic acid from a range of sugars, including glucose, sucrose and xylose, at concentrations of more than 100 g/L. After laboratory studies, the team recently piloted the process in 100-L and 300-L fermentation bioreactors.

“This bio-succinic acid production process was also the subject of a technoeconomic assessment that we conducted, which showed the process is economically competitive with chemically synthesized succinic acid,” Zhao says. The researchers are now looking for commercial partners to license the technology.

“This project is an important development for the industry because the methods could apply to other chemicals used in everyday products, and it further highlights how bioindustrial manufacturing can unlock a new future where everyday plastics, chemicals, materials, clothing and more are safely manufactured in the U.S. using biology,” said Melanie Tomczak, head of programs and chief technology officer at BioMADE (Twin Cities, Minn.; [www.biomade.org](http://www.biomade.org)), an organization supporting bio-industrial manufacturing innovation. BioMADE provided funding for the project.



## Successful pilot study of wastewater reuse technology at commercial site

**A** pilot project evaluating the Electro-Ceramic Desalination (ECD) technology developed by Membrion Inc. (Seattle, Wash.; [www.membrion.com](http://www.membrion.com)) successfully recovered clean water from the reject water of a reverse osmosis (RO) desalination process at a commercial manufacturing site.

Membrion’s technology uses ceramic membranes for ion separation in extreme environments where polymeric membranes would typically fail (see A New manufacturing approach for heavy-duty ceramic membranes, *Chem. Eng.*, May 2024, p. 11). The company developed a method for shaping silica into ceramic membrane sheets with pore sizes suitable for ion-transport. An electric field, rather than pressure, drives the migration of ions.

For the pilot project, an ECD unit was installed at a Colgate-Palmolive (New York, N.Y.; [www.colgatepalmolive.com](http://www.colgatepalmolive.com)) facility in Cambridge, Ohio, where it produced clean water for reuse over a four-week period from the facility’s RO desalination wastewater. The facil-

ity was chosen specifically because of its challenging water chemistry, says Greg Newbloom, Membrion CEO. The combination of RO and ECD concentrated the problematic ions in the RO reject water into a volume of 3 to 6% of the original water volume. Project leaders varied the water chemistry specifications required, and found that the ECD could deliver the water for reuse according to the desired properties, Newbloom said.

Based on the results of the pilot project, Membrion is now working with Colgate-Palmolive to expand the use of the ECD to several other facilities in water-stressed areas, with the goal of delivering 400 million gallons of water for reuse with the ECD across all the sites.

The pilot project was a part of the 100+ Accelerator program (New York, N.Y.; [www.100accelerator.com](http://www.100accelerator.com)), an industry consortium aimed at funding and developing sustainability-related technologies and approaches whose benefits could be shared across all member companies.

## A more mechanical method for methanol manufacture

The demand for “green” methanol as a low-carbon fuel is rising, making it a valuable commodity, as well as a promising avenue for waste-carbon utilization, especially since it can be readily produced from “stranded” carbon sources, such as flare gas. At its landfill-gas processing plant in Houston, Montauk Renewables, Inc. (Pittsburgh, Pa.; [www.montaukrenewables.com](http://www.montaukrenewables.com)) is planning a pilot plant to deploy a novel technology developed by Emvolon (Woburn, Mass.; [www.emvolon.com](http://www.emvolon.com)) to produce carbon-negative methanol from the site’s flare gas.

Emvolon’s process is very efficient and cost-effective at converting methane-containing streams, because its key technology utilizes a modified internal combustion engine (ICE) rather than a chemical reactor, resulting in a modular and scalable design.

“We operate the system to be very fuel-rich, and we’ve gone beyond anything that people have done in the literature. It is very difficult to ignite a mixture without any sort of external assistance once you have a very lean or rich mixture. It takes a lot of special controls to do this,” explains Emmanuel Kasseris, CEO of Emvolon.

The ICE has been specially tuned to handle this extremely fuel-rich environment to optimize it for the partial oxidation of a methane-containing stream into hydrogen and CO (syngas) instead of CO<sub>2</sub> and water. “We make very high hydrogen concentrations in our syngas, so we also make power that can be used to run some of the utilities,” comments Kasseris. The syngas is then com-

pressed and converted to liquid methanol using a conventional catalytic process. The pilot plant at Montauk Renewables is designed to produce over 15,000 gal/yr of green methanol, with plans to eventually expand to 2,400,000 gal/yr on that site.

“For the next generation of the technology, we have actually used the modified ICE as a compressor, reactor and expander to replace more expensive process equipment. We have gotten very high conversions, on par with the best reactors in the world using this engine technology,” adds Kasseris.

Within Emvolon’s modified catalytic diesel engine — based on a typical truck engine — the cylinders can be retrofitted with a custom catalyst-containing piston (photo). To further develop the process, Emvolon has partnerships underway with Waukesha and Clariant AG related to engine design and catalysis, respectively. ■



## Chementator Briefs

### SUSTAINABLE SMR

In the pursuit of lowering greenhouse gas emissions, hydrogen has gained much attention as a potentially “clean” energy source. Typically, hydrogen is produced by steam methane reforming (SMR), a process which itself produces greenhouse gases. Efforts to lower the carbon footprint of hydrogen production include producing “green” hydrogen via electrolysis, using carbon capture with SMR to produce “blue” hydrogen, as well as increasing the efficiency of the SMR process (see Methane Reforming: Solving the Hydrogen Blues, *Chem. Eng.*, October 2023).

Now, researchers at Rice University (Houston, Tex.; [www.rice.edu](http://www.rice.edu)) have developed a catalyst that allows the SMR reaction to be driven by light rather than heat, eliminating emissions from the reaction. When exposed to a specific wavelength of light, the copper-rhodium photocatalyst breaks down methane and water vapor into hydrogen and carbon monoxide, without external heating. Copper nanoparticles are used as the catalyst’s energy-harvesting “antennae.” Rhodium atoms and clusters were added to the catalyst system as reactor sites. The rhodium binds water and methane molecules to the plasmonic surface, tapping the energy to fuel

the SMR reaction.

The research also shows that the technology can avoid catalyst deactivation due to oxidation and coking, and effectively regenerate the catalyst with light. The technology can be used for on-demand hydrogen generation, which would avoid the need to transport the hydrogen gas over long distances. Peter Nordlander and Naomi Halas are the authors of a study about the research that was published in *Nature Catalysis*. Halas stated that “This research showcases the potential for innovative photochemistry to reshape critical industrial processes, moving us closer to an environmentally sustainable energy future.”

### CAPTURING CARBON FROM THE AIR

Capturing carbon dioxide from the air, known as direct air capture (DAC), is one of the promising tools in the arsenal of techniques for lowering atmospheric greenhouse-gas levels and slowing global warming. While some techniques for DAC work well for air that contains high concentrations of CO<sub>2</sub>, they may not be efficient in ambient air, where CO<sub>2</sub> concentrations are low.

Chemists at the University of California,

Berkeley ([www.berkeley.edu](http://www.berkeley.edu)) have developed a new type of absorbent that addresses this challenge. The porous absorbent is a covalent organic framework (COF) that they say captures CO<sub>2</sub> from ambient air without degradation by water or other contaminants. COFs are held together by covalent carbon-carbon and carbon-nitrogen double bonds, as compared to metal organic frameworks (MOFs), which are held together by metal atoms. The research has been reported in the journal *Nature* in October, by authors Omar Yaghi, professor of chemistry at UC Berkeley, and graduate student Zihui Zhou.

Yaghi and Zhou, together with colleagues, developed COF-999, which is assembled from a backbone of olefin polymers with an amine group attached. The porous material is flushed with more amines that attach to NH<sub>2</sub> and form short amine polymers inside the pores. Each amine can capture about one CO<sub>2</sub> molecule. The COF can capture CO<sub>2</sub> at room temperature. Heating the COF to a mild temperature of about 140°F releases the CO<sub>2</sub>, rendering the COF ready for reuse. The material reportedly holds up to 2 millimoles of CO<sub>2</sub> per gram. Yaghi noted that it may be possible to enlarge the pores to capture even more CO<sub>2</sub>. ■

## Plant Watch

### Evonik breaks ground on specialty-amine production plant in Nanjing

November 11, 2024 — Evonik Industries AG (Essen, Germany; [www.evonik.com](http://www.evonik.com)) has broken ground on its plant expansion for specialty amines in Nanjing, China. The Nanjing plant specializes in producing amine-based additives that play a significant role as catalysts during polyurethane foam formation.

### Shell Chemicals Park Moerdijk starts up waste-plastics processing unit

November 11, 2024 — Shell plc (London, U.K.; [www.shell.com](http://www.shell.com)) announced that Shell Chemicals Park Moerdijk started up a new unit that allows difficult-to-recycle plastics, like food packaging, to be reused. With the new unit — called the Market Development Upgrader (MDU) — the Moerdijk complex can now upgrade plastic-waste raw materials at scale into pyrolysis-based feedstock for the site's hydrocarbon-cracking processes. Moerdijk is the first location within Shell to upgrade pyrolysis oil at scale.

### SABIC launches \$170-million resin manufacturing facility in Singapore

November 7, 2024 — SABIC (Riyadh, Saudi Arabia; [www.sabic.com](http://www.sabic.com)) announced the official launch of its new \$170-million resin manufacturing facility in Singapore. The new facility supports SABIC's goal of increasing global specialty-resin production by more than 50%.

### Clariant expands storage capacity for recycled mono-propylene glycol

November 7, 2024 — Clariant AG (Muttens, Switzerland; [www.clariant.com](http://www.clariant.com)) is expanding its storage capacity in Scandinavia for the use of recycled mono-propylene glycol (MPG) used in aircraft deicing fluids. Two new storage tanks and a truck unloading station have been installed at the company's Uddevalla facility in Sweden to increase capacity and optimize handling of the product. This development helps Clariant to maximize the reuse of MPG, which can be collected from the run-off of deicing operations at local airports and processed into industrial-grade glycol.

### BASF opens new production line for water-based dispersions

November 5, 2024 — BASF SE (Ludwigshafen, Germany; [www.basf.com](http://www.basf.com)) recently opened a new production line for water-based dispersions in Heerenveen, the Netherlands. The new unit will be electrically powered and supplied with renewable electricity from the Hollandse Kust Zuid wind farm, which BASF operates in a joint venture with Vattenfall and Allianz. The

new production line will significantly increase production of polymer products used in inks for food packaging and to optimize the color and gloss of various types of paints and varnishes.

### Veolia and Morocco to establish Africa's largest desalination project

November 5, 2024 — Veolia (Paris, France; [www.veolia.com](http://www.veolia.com)) and the Kingdom of Morocco plan to establish a strategic partnership to develop, on an exclusive basis, a seawater desalination project that will be the largest in Africa and the second largest in the world. With a capacity of 822,000 m<sup>3</sup> of drinking water per day, the plant will serve the Rabat-Salé-Kénitra and Fès-Meknès regions to meet the water needs of nearly 9.3 million inhabitants.

### LanzaTech and Eramet announce plans for integrated CCUS project in Norway

November 5, 2024 — LanzaTech Global, Inc. (Chicago, Ill.; [www.lanzatech.com](http://www.lanzatech.com)) plans to develop a commercial-scale, integrated carbon capture, utilization and storage (CCUS) facility at Herøya Industrial Park in Porsgrunn, Norway. The plant will produce ethanol from captured CO<sub>2</sub> and is expected to begin operations in 2028. Eramet Group (Paris, France; [www.eramet.com](http://www.eramet.com)) will supply furnace gas as feedstock to the facility from the Porsgrunn Manganese Alloys smelter. The new facility's maximum production capacity is expected to be 24,000 m.t./yr of fuel-grade ethanol.

### ALPLA opens PET recycling plant in South Africa

November 1, 2024 — ALPLA Group (Hard, Austria; [www.alpla.com](http://www.alpla.com)) has launched a new polyethylene terephthalate (PET) recycling plant in Ballito, South Africa. The company has invested €60 million in the new plant, which is able to produce up to 35,000 m.t./yr of recycled PET flakes and pellets, which will then be further processed into sustainable plastic packaging at ALPLA's production plant in Lanseria, South Africa.

### MilliporeSigma investing \$76 Million to expand manufacturing facility in St. Louis

October 31, 2024 — MilliporeSigma (Burlington, Mass.; [www.sigmaaldrich.com](http://www.sigmaaldrich.com)) announced a \$76-million expansion of its antibody-drug conjugates (ADC) manufacturing capabilities and capacity at its Bioconjugation Center of Excellence facility in St. Louis, Mo. This investment will triple existing capacity at the site and enhance the company's contract development and manufacturing organization (CDMO) offering. The project will also add new laboratories, a dedicated buffer-preparation facility and cold-storage capacity.

## LINEUP

ALPLA
ASAHI KASEI
BASF
CLARIANT
ERAMET
EVONIK
LANZATECH
LINDE
MILLIPORESIGMA
SABIC
SHELL CHEMICALS
SOLENIS
TECHNIP ENERGIES
TORAY
VEOLIA



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### **Linde starts up supply of industrial gases to PT Freeport Indonesia**

October 31, 2024 — Linde plc (Guildford, U.K.; [www.linde.com](http://www.linde.com)) started up the supply of oxygen and nitrogen to PT Freeport Indonesia's new copper smelter and refining facility in Manyar, one of the largest copper-processing sites in the world. Linde has invested \$120 million in the new onsite air separation unit (ASU), the largest in Indonesia and Linde's largest ASU in southeast Asia. Linde's new ASU will also supply liquefied industrial gases to new and existing bulk customers in East Java.

### **BASF to expand capacity for expandable polystyrene**

October 24, 2024 — BASF is expanding the production capacity for Neopor expandable polystyrene by 50,000 m.t./yr at its site in Ludwigshafen. Startup of the new production facility is scheduled for early 2027. Neopor is a graphite-containing, expandable polystyrene granulate that is primarily used as a raw material for the production of insulation materials.

### **Mergers & Acquisitions**

#### **Solenis acquires BASF's mining flocculants business line**

November 5, 2024 — Solenis (Wilmington, Del.; [www.solenis.com](http://www.solenis.com)) has acquired BASF's flocculants business for mining applications. The acquired product portfolio includes flocculants and other products used for solid-liquid separation and material handling in mining and mineral-processing applications.

#### **Toray Advanced Composites acquires Gordon Plastics**

November 5, 2024 — Toray Advanced Composites USA (Morgan Hill, Calif.; [www.toraytac.com](http://www.toraytac.com)) expanded its portfolio for continuous fiber-reinforced thermoplastic composite materials by acquiring the assets of Gordon Plastics. The acquisition includes a 47,000-ft<sup>2</sup> manufacturing facility near Denver, Colo., which produces continuous-fiber-reinforced composite tapes made with many matrices, including polyetherimide, polyphenylene sulfide, polyester and various polyamides, reinforced with a wide range of glass- and carbon-fiber types.

### **Asahi Kasei and Honda form battery-separator JV in Canada**

November 5, 2024 — Asahi Kasei Corp. (Tokyo; [www.asahikasei.com](http://www.asahikasei.com)) and Honda Motor Co. plan to convert E-Materials Canada Corp., a wholly owned subsidiary of an Asahi Kasei subsidiary in Canada, into a joint venture (JV) between Asahi Kasei and Honda. Honda will invest a total of approximately \$300 million in this JV, which will produce separator materials to be utilized for lithium-ion batteries. The JV will be headquartered in Port Colborne, Ont., Canada, and will comprise 75% stakeholding by Asahi Kasei and 25% stakeholding by Honda Canada Inc.

#### **Technip Energies acquires two engineering companies in Rome**

October 31, 2024 — Technip Energies (Paris, France; [www.ten.com](http://www.ten.com)) has acquired the businesses of GST s.r.l. and Energeco s.r.l., two engineering companies based in Rome, Italy. GST and Energeco specialize in process engineering and piping design. ■

*Mary Page Bailey*

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## The Case of the Lying Gamma Scan

Henry Kister shares lessons learned from troubleshooting distillation towers

This conversation started in a course I was presenting in Sydney, Australia. I was about 15 minutes into my presentation when a delegate from a major petroleum refinery stopped me.

"How long will you be talking to us about gamma scans?" he asked.

"For the next 90 minutes," I replied.

"Do you realize you are wasting our time?" He then paused, noticing that everyone was looking at him, and qualified: "I heard that gamma scans work in Texas and in the U.K., but they do not work in the Southern Hemisphere."

"They used to work when I was in Australia, I am not sure what you guys did to them after I left," I said.

"Well maybe you ought to come back and fix them up, because at present they do not do any good here," was his response.

"I think you have a good story to tell us, so let us hear it," I replied.

"With pleasure," he replied. "We had noticed diesel components in our vacuum tower." [It is important to note here that when a refinery vacuum tower has no diesel-recovery section, these components should not be present, because the vacuum-tower gas-oil products are of much lesser value than diesel. The atmospheric crude tower has a stripping section (typically about six trays) that steam-strips the diesel components, keeping them out of the vacuum tower feed. The presence of diesel in the vacuum tower indicates that the stripping section is not working properly.]

The delegate continued: "We suspected loss or damage of the stripping trays — this is a frequent occurrence in this type of service. Pockets of water in the stripping steam or high liquid levels in the sump generate strong upward push that dislodge or damages these trays."

"To confirm, we had the trays gamma scanned, and their report concurred that the trays were gone. So we shut the unit down to repair, opened the tower, and there were the trays, all in place, nice and clean

and shiny, laughing at us. And after this, you want me to sit through another one and a half hour of this," continued the gamma-scan skeptic.

I asked a very important question: "Did you do any process checks?"

"Do you know how much money a gamma scan costs in Australia? For what we pay them, you'd think they would tell us everything," he answered. At that time, Australia did not have local gamma-scanning service providers, meaning that scanners and equipment had to be transported from overseas. This made the cost an order of magnitude higher than in the U.S. Gulf Coast region.

"It does not work this way. They have the radiation expertise, but it is you that has the process, operation and tower knowledge. The two resources need to be combined," I then added. "Could you have been operating at turndown?"

"Turndown!" He laughed. "We do not use this word in our refinery. Everything is pushed to the limit."

"I have seen many atmospheric crude towers pushed to the limit above the feed, but their stripping sections operate at turndown." I then asked if they had a can (a smaller-diameter cylinder that contains the stripping trays to avoid turndown issues) in the stripping section.

"No we don't. And you are barking up the wrong tree. We do not have turndown issues," he insisted.

At this point one of his colleagues intervened. "I have the simulation here. We can check after the class."

After the class, we sat together and calculated the stripping section  $C$ -factor. The  $C$ -factor (ft/s) is the superficial vapor velocity,  $U$  (ft/s), based on the active area of the tray, adjusted for vapor and liquid densities ( $\rho_G$  and  $\rho_L$  respectively), as expressed in Equation (1):

$$C = U[\rho_G/(\rho_L - \rho_G)]^{1/2} \quad (1)$$

The  $C$ -factor we calculated was 0.03 ft/s. The maximum  $C$ -factor of trays like this would be 0.4 ft/s. The

trays were operating at less than 10% of their maximum rate, at a 13:1 turndown.

"Do you know what hydraulic condition you will have on the trays at this turndown?" I asked.

"Weeping, I guess," he muttered.

"All the liquid will weep. It is called dumping. There will be very little liquid on the trays. Gamma scans are shot every 2 in. The tray is 0.1 in. thick. Gamma scans easily miss a dry tray, and often would not be able to tell the difference between a dry tray and a missing tray. Gamma scans do not see trays; they see liquid sitting on the trays," I explained.

At which point he uttered "I do not like what you are telling me."

"I did not think you would," I replied.

"You are telling me that I did not need to shut the unit down. Had I known this, all I would have needed to do is triple the stripping steam rate [note that raising the stripping steam rate may require a small reduction in charge rate if there is a constraint above the feed, but is quite acceptable to do for a short-term test] and do another scan. I would then have seen liquid on the trays," he said.

"You are right on the money."

**Takeaway:** Remember, you are the doctor, and the scanners are analogous to the X-ray technologists. Until you bring the two resources together, you do not have a good diagnosis.

*Edited by Mary Page Bailey*

### Author



**Henry Z. Kister** is a Senior Fellow and Director of Fractionation Technology at Fluor Corp. (email: [henry.kister@fluor.com](mailto:henry.kister@fluor.com)). He has over 35 years of experience in design, troubleshooting, revamping, field consulting, control and startup of fractionation processes and equipment. He is the author of three books, the distillation equipment chapter in Perry's Handbook, and about 150 articles. Kister has taught the IChemE-sponsored "Practical Distillation Technology" course over 550 times in 26 countries. A recipient of several awards, Kister obtained his BE and ME degrees from the University of NSW in Australia. He is a member of the U.S. National Academy of Engineering, Fellow of IChemE and AIChE, and serves on the FRI Technical Advisory and Design Practices Committees.

# Level Up

Advanced level measurement devices enhanced with intelligence solve CPI challenges

**C**hemical processes often require handling media that is corrosive, flammable, explosive or toxic with wide ranges in temperature and pressure and characteristics that include steam, dust, foam, turbulence and condensation. All these factors, often in combination, can make it challenging for level instrumentation to provide accurate and reliable measurements. However, today's non-contact and radar-based level measurement technologies enhanced with intelligence solve the industry's biggest level measurement challenges.

"The primary obstacles for chemical processors in level measurement and control stem from the nature of the materials being processed," explains Brittany Cost, level product manager with SOR Controls Group (Lenexa, Kan.; sorinc.com). Some of the greatest challenges include the following:

- Corrosive media: Many chemical processes involve handling highly corrosive substances like acids, bases or solvents, which can damage traditional sensors.
- Harsh environments: High pressures, extreme temperatures and abrasive materials can damage measurement devices, leading to inaccurate readings and equipment failure.
- Tank configurations: The geometry of tanks, presence of agitators and interference from internal structures can cause measurement errors.
- Foaming or turbulence: In some processes, foaming or turbulence can create false readings for certain types of level sensors.
- Viscous or sticky materials: Thick, sticky or viscous materials can interfere with sensor surfaces, leading to inaccurate readings.
- Safety and compliance: Ensuring level measurement meets strict safety standards and regulatory requirements is essential to avoid risks in chemical processing.

"When attempting to measure and control level in diverse and challenging applications, the greatest needs for level measurement and control equipment in chemical plants revolve around ensuring precision, reliability and safety," says Jenny Leion, industry manager for chemicals, with Emerson (Shakopee, Minn.; emerson.com).

"Beyond accuracy, ease of installation and maintenance are key considerations," Leion continues. "Modern chemical plants require instruments that integrate seamlessly with digital control systems, while providing self-diagnostics to minimize downtime. Instruments should be capable of handling harsh environments while still providing consistent performance."

"Furthermore, advanced level measurement devices should support enhanced connectivity and data analytics," says Leion. "The ability to gather, transmit and analyze reliable process data is crucial for optimizing production, reducing operational costs and enabling predictive maintenance strategies. This data-driven approach helps improve overall process efficiency, enhances safety and supports sustainable operations in this increasingly complex and regulated industry."

To that end, providers of instrumentation are leveling up their game when it comes to level measurement devices with the introduction of advanced instrumentation that is enhanced with intelligence to provide solutions to many level measurement issues.

## Digitalization is key

"How can today's smart instruments help chemical processors produce more prod-

ucts with fewer resources? This is one of the major challenges most facilities are facing," says Keith Riley, national product manager for Endress+Hauser USA (Greenwood, Ind.; us.endress.com). "The need for added value beyond the primary measurement can be categorized into one of three areas: simplicity, safety and increased productivity."

He says these are achieved using a variety of improvements, including:

- Human-machine interfaces (HMI) that are more intuitive and informative
- Instrument-led commissioning to reduce human error and time
- Tools that allow plant personnel to diagnose instruments in situ, reducing the need for technicians to enter hazardous environments
- Preventive diagnostics to reduce

Emerson



**FIGURE 1.** The Rosemount 3408 non-contacting radar level transmitter is a frequency modulated continuous-wave radar instrument suitable for level measurement and over-fill prevention. Its smart features maximize efficiency for trouble-free operations, simplifying commissioning, operation and testing

unscheduled downtime due to instrument issues

- Predictive diagnostics through condition-based monitoring of the process

"These technologies eliminate the need for multiple interface tools, improve installation and commissioning time by more than 30%, reduce unplanned and reactive shutdowns, detect process anomalies using predictive maintenance and reduce systematic failure and on-site accidents," says Riley.

Emerson's Leion adds: "When modern level instruments are equipped with advanced diagnostic tools that can monitor their own health and performance, they allow operators to identify potential issues before they lead to equipment failure or process disruption, thus minimizing unplanned downtime and reducing the need for reactive maintenance."

Leion continues: "The industry is really on a digitalization journey with intelligent field instruments providing more process data. New connectivity options, such as Bluetooth, Ethernet-APL and 5G and wireless solutions like WirelessHART are

transforming how data are transported throughout facilities and to and from remote locations.

Endress+Hauser's Riley agrees: "Industrial Ethernet-APL is experiencing increasing application in chemical level-measurement processes, opening the door to numerous critical process and diagnostic datapoints becoming available to an overarching plant control system at a much higher communication speed.

"Some of this data has been available via HART for a long time, but it was often 'trapped' in instruments due to a lack of a HART communication gateway for the host controller to use. Ethernet standardization is making this data much more usable in control systems, adding significant value beyond a single process variable," Riley continues. "This is empowering operations and engineering personnel with the right information at the right times, minimizing the need to mine data manually from a process historian."

The availability of modern architectures is paving the way to wider adoption of intelligent field devices connected to higher level systems, enabling more robust, flexible and faster data access, which addresses yet another key challenge faced by chemical processors — the pressure to meet strict sustainability targets.

"This includes reducing emissions, minimizing waste and optimizing energy use. Advanced digitalization and smart instrumentation play a pivotal role here because they provide the precise, real-time data needed for more efficient resource management," says Emerson's Leion. "By offering greater process insight, these technologies help optimize production processes, minimize material usage and ensure that equipment operates within optimal parameters, thereby reducing environmental impact."

At the same time, safety remains a critical concern,

Hawk Measurement



**FIGURE 3.** Hawk's Centurion Guided Radar level transmitter for measuring liquids, sludge, powders and granules for level and interface measurement is not affected by pressure, temperature, viscosity, vacuum, foam, dust, changes in dielectric constant or coating of the probe



**FIGURE 2.** SOR's 1100 Series MLI was designed to overcome issues with corrosive media and harsh environments. It can incorporate external point level switches or continuous level transmitters, such as guided wave radar or magnetostrictive level transmitters, without breaking the pressure boundary or disturbing any existing piping

particularly when handling hazardous chemicals. "Technologies like Smart Meter Verification and remote proof testing of level instrumentation are making significant strides in enhancing safety and reliability," says Leion. "When operators can verify the health of their level instruments without needing to stop the process or physically access hazardous areas, it ensures that the instruments are functioning properly and reduces the risk of human error and accidents associated with manual intervention. And, remote proof testing allows safety instrumented systems to be tested and validated from a safe, remote location, further improving plant safety, while reducing the need for costly shutdowns."

### Technology for every challenge

In addition to intelligence and connectivity enhancements, recent developments have advanced level measurement technologies to come down in price and complexity, which has led to a shift away from traditional technologies to non-contact and radar-based solutions that offer accuracy and reliability, even in harsh conditions, solving some of the industry's biggest level measurement challenges, according to the experts.

Sreekanth Madhavasherry Sreenivasan, global product line market manager and global product manager for the level product line with



**FIGURE 4.** ABB's LWT Series guided-wave radar accurately detects level even in demanding applications that previously did not respond well to guided wave radar, including those with fast-moving levels and emulsion

ABB (Zurich, Switzerland; [www.abb.com](http://www.abb.com)), says, "Numerous applications within the chemical industry impose significant challenges on measuring instruments. Specifically, factors such as steam, dust, foam, turbulence and condensation complicate the functionality of level measuring devices, impacting their precision and dependability."

"In addition to these media characteristics, chemical processes entail handling toxic, corrosive, flammable or explosive materials with wide variations in temperature and pressure," Sreenivasan continues. "Yet, processors are expected to overcome these industry challenges while still increasing performance targets."

"For this reason, level measurement solutions in the chemical industry must be tailored to diverse applications, each with unique challenges, depending on the process conditions. Today's advanced technologies address a variety of issues related to accuracy, safety, maintenance and process optimization," suggests Emerson's Leion.

### Corrosive environments

For example, non-contacting level measurement technologies, such as radar, are ideal for use in mixing tanks and reactors where corrosive, viscous or agitated media are present. "These environments pose significant challenges for traditional contact-based sensors, which can be affected by build-up, corrosion

or fouling. Rosemount non-contacting radar with Smart Echo Supervision is beneficial in these applications because it tracks all signal echoes, including those caused by internal obstructions, such as nozzles, baffles or agitators," explains Leion. "The Rosemount 3408 non-contacting radar level transmitter (Figure 1) is a frequency modulated continuous wave radar instrument suitable for level measurement and overflow prevention."

The smart features save time and maximize efficiency for trouble-free operations, simplifying commissioning, operation and testing. Diagnostics help users proactively plan maintenance and optional Bluetooth provides wireless connectivity for convenient configuration and maintenance. Verification at scheduled intervals can be conducted from the control room without process interruptions and proof-testing can be done remotely and in-situ with on-board functionality.

SOR's Brittany Cost agrees: "Non-contact sensors, such as radar and ultrasonic sensors have gained popularity because they do not encounter process material, making them ideal for corrosive or hazardous substances and can avoid issues related to build up or fouling that affect traditional sensors. In addition, modern guided wave radar can withstand extreme conditions and still provide accurate measurements."

To that end, SOR's 1100 Series MLI (Figure 2) was designed to help processors overcome issues with corrosive media and harsh environments even in challenging tank configurations. It can incorporate external point level switches or continuous level transmitters, such as guided wave radar or magnetostrictive level transmitters, without breaking the pressure boundary or disturbing any existing piping, says Cost.

"The 1100 Series MLI features specialty materials, ensuring resistance to corrosive chemicals and operation in extreme environments, such as cryogenic applications, with its special chamber

design, which is particularly suited for demanding applications like liquid propane gas," she explains. "The device serves as an alternative to traditional sight glasses since the vessel contents are totally contained within the float chamber, making it ideal for high-pressure systems. These features ensure that the 1100 Series offers reliability and ease of use while helping chemical processors maintain compliance and optimize safety in demanding conditions."

Tres Thurston, sales manager with Hawk Measurement (Medina, Ohio; [hawkmeasurement.com](http://hawkmeasurement.com)), adds that radar-based technologies, particularly guided wave radar, provide a lot of opportunities in demanding level measurement applications. "With guided wave radar, the part of the instrument that is coming into contact with the media and exposed to high temperatures or pressures is constructed of very robust, rugged industrial materials that aren't impacted by extreme temperatures, high pressures or caustic environments," says Thurston. "And, guided wave radar has a tendency to be more accurate than other technologies such as ultrasonic or free air radar, despite harsh environments."

He says Hawk's Centurion Guided



VEGA Americas

**FIGURE 5.** VEGA's VEGAPlus series non-contact radar can take measurements, even in dusty applications, and has the ability to measure through plastic, glass or fiberglass tanks without the need for a process connection



**FIGURE 6.** Micropilot FMR60B can be used for continuous non-contact level measurement of liquids, pastes and slurries. Measurements are not affected by changing media, temperature changes, gas blankets or vapors

Radar (CGR) level transmitter (Figure 3) is ideal for measuring liquids, sludge, powders and granules for level and interface measurement. This technology is not affected by pressure, temperature, viscosity, vacuum, foam, dust, changes in dielectric constant or coating of the probe. "In addition, CGR features Power over Ethernet (PoE) communication. The advantages to PoE connectivity include secure in-plant and remote monitoring, remote sensor setup, diagnostics and troubleshooting abilities."

### Challenging process conditions

ABB's Sreenivasan adds that newer guided wave radar technologies with advanced software algorithms and semiconductor technology, such as is found in ABB's LWT Series guided wave radar (Figure 4), accurately detect level even in demanding applications that previously did not respond well to guided wave radar, including those with fast moving levels and emulsion. "For example, due to emulsion having its own dielectric, the time of flight will change through this layer like the change experi-

enced through the lower dielectric layer, so applications with changing dielectric constants are a challenge for traditional guided wave radar.

"However, with the advanced software algorithms and semiconductor technology, ABB's guided wave radar meets the challenges of these applications thanks to our Level Expert algorithm. This firmware enables accurate readings, even in changing dielectric constant environments."

And, for issues related to dust, vapor and condensation, which are "without a doubt the biggest challenges" when it comes to level measurement in the chemical industry, non-contact radar is a good solution, says Jason Kuzmiak, chemical industry sales specialist with VEGA Americas (Mason, Ohio; [vega.com](http://vega.com)).

"For example, in the petrochemical field of plastic pellets, dust can be difficult to measure through when trying to obtain accurate pellet level indication. Historically guided wave radar and other mechanical devices were used to take these measurements, but now non-contact radar technologies can be used."

VEGA's VEGAPlus series (80 GHz) non-contact radar (Figure 5) can take measurements, even in dusty applications, and has the ability to measure through plastic, glass or fiberglass tanks without the need for a process connection. The instrument also comes with Ethernet-APL, offering fast, secure data transmission, even in challenging chemical environments, to provide faster, more secure connections for field-located instruments.

"This allows data transmission, high-speed delivery of process updates, easy access to diagnostics, settings and protocols using a standard web browser and secure data transmission, even in hazardous areas," he explains. "And available Bluetooth and remote displays allow end users to commission,

monitor and adjust parameters as needed from any location."

Foaming, another common level measurement obstacle, is also being managed with newer technologies, says Endress+Hauser's Riley. "Many processes produce foam and keeping it from entering discharge pipes, where it can clog filters and produce other issues, can pose a challenge," says Riley. "A free-space radar level sensor, such as the Micropilot FMR60B (Figure 6), can detect foam formation in the process and communicate its presence to a host controller via HART communication. This can trigger the application of a foam retardant through the plant control system, as well as continuous feedback to facilitate precise dosing, delivering the required amount to keep foam at bay while eliminating overshoot of expensive agents and the need to scrub it from finished product."

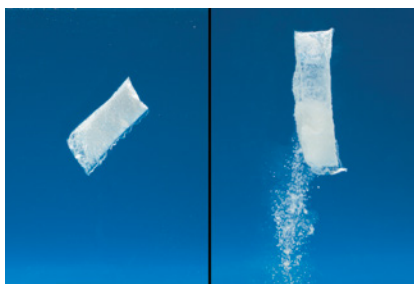
Micropilot FMR60B is an 80-GHz radar developed according to the international functional safety directive International Electrotechnical Commission (IEC; Geneva, Switzerland; [www.iec.ch](http://www.iec.ch)) IEC 61508 standard. The free-space radar offers maximum reliability due to the drip-off antenna, improved algorithms and small beam angle. The drip-off antenna is suited for free-space applications and offers high beam focusing for vessels with many internal fittings.

The instrument is used for continuous non-contact level measurement of liquids, pastes and slurries and measurements are not affected by changing media, temperature changes, gas blankets or vapors. It also possesses the smart sensor functionality, Heartbeat Technology.

"The latest level measurement technologies are highly adaptable to the chemical process industries' diverse applications," notes Leion, adding, "These level technologies provide reliable solutions to challenges related to process efficiency, safety and maintenance, ensuring that operations run smoothly and sustainably, while also reducing downtime and improving overall plant performance."

Joy LePree

# Packaging

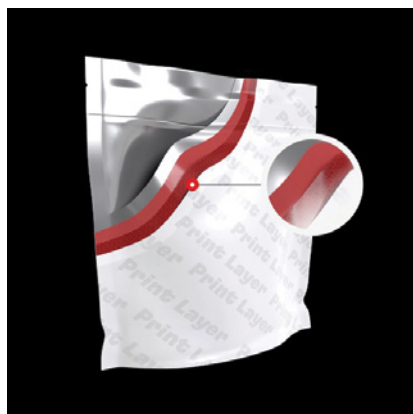


Cortec Corp.

## This packaging film is water soluble

EcoSol® is a PVOH (polyvinyl alcohol) film (photo) that dissolves in water in minutes. It can be made into bags, pouches and sachets of many different sizes to create an efficient delivery system for a wide range of products, including the following: detergents; concrete additives; water-treatment chemicals; agricultural treatments; and bathing products. Packaging products in EcoSol pouches allows precise dosing and avoids the messiness associated with trying to measure and apply powder products — especially in windy conditions. EcoSol is especially beneficial for packaging chemicals because it eliminates the need for direct handling. Although EcoSol is designed to break down in contact with water, it can be stored for two years if kept in dry conditions at room temperature in the original barrier bags. After immersion, EcoSol dissolves in water, leaving a harmless, non-toxic, PVOH solution and releasing the packaged product. Once the solution of PVOH comes into contact with common microorganisms, conversion to carbon dioxide and water takes place within about 30 days. — *Cortec Corp., St. Paul, Minn.*

[www.coretecvc.com](http://www.coretecvc.com)



Henkel Adhesive Technologies

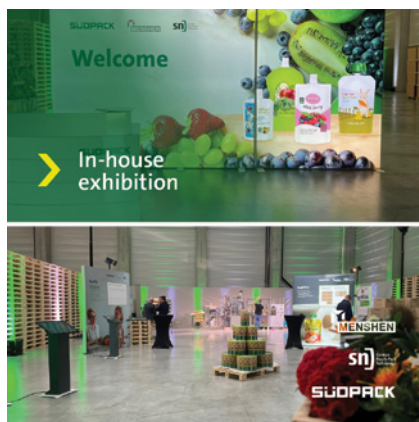
## These films make recycling easier for dry-food packaging

Three-layer, multi-material packaging is common for effectively protecting dry food from the environment, but the combination of materials makes this type of film difficult to separate and therefore difficult to recycle. The Liofol product range offers significant benefits to film and packaging manufacturers, with both offline and inline coating options (photo). Due to its excellent oxygen-barrier properties, the coating enables a new packaging design using only one material. This reduces the amount of material used in food packaging without compromising quality and integrity. It is also certified recyclable by cyclos-HTP

and recognized by the Association of Plastic Recyclers (APR) as meeting the Critical Guidance Protocol for polyethylene (PE) films and flexible packaging. Because mono-material packaging does not need to be separated into different components, the recycling quality is increased while the effort and cost of recycling is reduced. The oxygen barrier layer can be applied to OPP (oriented polypropylene) and PE films at high machine speeds in excess of 150 to 200 m/min and a weight of less than 1 g/m<sup>2</sup> in both flexo and gravure printing processes, and is also characterized by excellent transparency. This company's cooperation with Panverta Cakrakencana, one of the leading film manufacturers in Indonesia, has successfully provided a solution to improve the oxygen barrier performance of metallized cast polypropylene (CPP) and aluminum oxide coating (AlOx) films. The joint development has ensured that these vital oxygen-barrier properties for dry-food packaging can be achieved when switching from multi-material designs to mono-material polypropylene (PP). — *Henkel Adhesive Technologies, Dusseldorf, Germany*

## A packaging machine for spouted polypropylene pouches

This packaging machine, the result of a collaboration among three companies (photo), enables flexible, highly efficient in-house production of spouted pouches in various sizes and shapes, including the processing of different spout types. At its core is the high-performance SPM 50 packaging machine from SN Maschinenbau, which works seamlessly with mono-materials. The polypropylene-based (and therefore recyclable) high-performance films for pouch production are provided by this company while the corresponding spouts come from Menshen. The materials and machine settings are perfectly aligned, achieving optimal packaging results with maximum tightness and burst-pressure resistance. Manufacturers and packaging



SUDPACK verpackungen SE &amp; Co. KG

companies that process fruit purees, smoothies and other liquid or pasty foods requiring thermal treatment after filling will benefit from these advantages. By producing pouches from roll stock material and using spouts delivered in cardboard boxes, material costs can potentially be cut in half, while logistics and handling expenses are also significantly reduced, say the companies. — *SÜD-PACK Verpackungen SE & Co. KG, Ochsenhausen, Germany*  
[www.suedpack.com](http://www.suedpack.com)

### This packaging is designed for recycling in fiber streams

A collaboration between two companies developed a novel biopolymer-coated paper packaging solution (photo) that is designed for food applications requiring grease and oxygen barriers. Traditionally, the challenge of combining extrusion coating with paper lies in the adhesion of the coating to the paper, especially with biobased or biodegradable extrusion coatings. The solution developed by UPM Specialty Papers and Eastman helps resolve this issue by integrating biobased and compostable Solus performance additives with BioPBSTM polymer to form a thin coating onto UPM's compostable and recyclable barrier base papers. Thanks to the thinness of the coating layer, the solution is designed for recycling within existing fiber-recycling streams, empowering brands to adopt sustainable packaging. The new biopolymer-coated solution provides a new option for difficult-to-pack foods. This packaging material offers exceptional heat sealability while maintaining barrier protection when folded, making it suitable for flexible packaging. Furthermore, this technology is compatible with conventional LDPE (low density polyethylene) extrusion coating equipment, requiring no additional capital investment. — *Eastman Chemical Co., Kingsport, Tenn.*  
[www.eastman.com](http://www.eastman.com)

### This tube filler has interchangeable parts

The FP10 Tube Filler (photo) has an innovative hot-air tube heating system and a mechanical design that allows excellent accessibility from all sides. Maximum process reliability is assured via servo technology,

and changeovers can be performed quickly. For manufacturers running other models of tube-filling equipment from this company, the FP10's format and product contact parts are interchangeable throughout the entire FP Series. Capable of filling and closing up to 70 tubes per minute, the FP10 can handle metal, plastic or laminated tubes. The FP10 Tube Filler is operated via a touch panel with an intuitive, ergonomic user interface. Remote servicing is available via WiFi. The FP10 will be paired with two of this company's cartoning machines: either the VI 5 vertical cartoner, a unit suitable for a wide array of primary packages including bottles, vials, blister packs, jars, pouches and other similar components, and can produce up to 75 cartons per minute; or the CH 4 horizontal cartoner. This innovative machine platform can be offered in either intermittent or continuous motion, and has the flexibility to handle carton opening from either direction. — *IWK Packaging Systems Inc., Parsippany, N.J.*  
[www.iwkpackaging.com](http://www.iwkpackaging.com)

### Detect packaging leaks with non-destructive testing

Leak tests on packaging during production serve to ensure product safety and consumer protection. In the case of vacuum-sealed coffee capsules and packaging, manufacturers attach particular importance to quality features, such as freshness, aroma and flavor intensity. This company has easy-to-use systems for applications where quality requirements are particularly high. The Contura S400 Series (photo) detects leaks in packaging using a non-destructive method and can be easily integrated into production. During evacuation of the test chamber, two flexible membranes enclose the test objects so that they remain intact. If there is a leak, gas from the packaging penetrates into the evacuated test chamber — causing a measurable increase in pressure in the vacuum of the chamber. Gross leaks and micro leaks of less than 10 µm are detected in seconds. The Contura S also has a user-friendly color display. — *Inficon GmbH, Cologne, Germany*  
[www.inficon.com](http://www.inficon.com)

■  
 Scott Jenkins



Eastman Chemical Co.



IWK Packaging Systems Inc.



Inficon GmbH

## Steam Trap Operation

Department Editor: Scott Jenkins

Steam is commonly used across the chemical process industries (CPI) for a variety of end uses, including process heating, mechanical drive, moderation of chemical reactions and fractionation of hydrocarbons. Heat exchangers, turbines, fractionating towers, stripping columns, and reaction vessels are examples of equipment types for which steam is used. As the steam's energy is transferred to the system (for example, by the transfer of its latent heat to a process fluid, or by transforming its energy to mechanical work to drive rotating machinery), the steam condenses and is removed as a liquid via a steam trap. This one-page reference reviews the operation of steam traps and outlines the different types of steam traps available.

### Steam trap function

Steam traps are automatic valves that remove condensate (condensed steam) and non-condensable gases (such as air) without allowing steam to escape. Steam leaks sap the efficiency of the steam system. In general, steam traps work by keeping steam in the system's "steam loop" while extracting air and condensate (water) and redirecting it to the "condensate loop."

If steam traps do not function properly, excess steam will flow through the end-use device or the condensate will back up into it. Excess steam loss will lead to more costly operation, while condensate backup will reduce performance and may lead to waterhammer [7].

Steam traps should be located at the lowest natural and incidental low points (low points created by closing a valve) in the steam system. Steam traps are often installed at the following locations: Placed at 50- to 150-ft intervals of straight pipe; after every heat exchanger; and at every place where there are changes in elevation or pressure.

### Steam trap purposes

Steam traps serve several important functions in industrial operations, in-

cluding the following:

#### **Preventing steam waste.**

Steam traps automatically drain condensate from steam systems while keeping live steam from escaping.

**Saving energy.** Steam traps help prevent steam leaks, which can waste energy.

#### **Removing non-condensing**

**gases.** Steam traps remove air and other non-condensing gases from the system.

**Protecting equipment.** Steam traps protect steam systems from damage caused by prolonged exposure to condensate, such as corrosion and inconsistent heat delivery.

**Ensuring efficient heating.** Removing air from the system ensures even heating and delivers steam in as dry a state as possible.

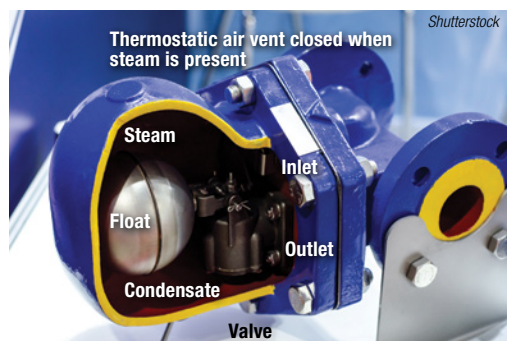
### Steam trap types

Steam traps generally fall into one of three main categories: mechanical, thermodynamic and thermostatic. These categories are described in the International Organization for Standardization (ISO; Geneva, Switzerland; [www.iso.org](http://www.iso.org)) standard ISO 6702: 1982 [2].

**Thermostatic traps.** Thermostatic traps use temperature differential to distinguish between condensate and live steam. This differential is used to open or close a valve. Under normal operating conditions, the condensate must cool below the steam temperature before the valve will open. Common types of thermostatic traps include bellows and bimetallic traps [7].

**Mechanical traps.** Mechanical traps sense the difference in density between condensate and live steam and use that to produce a change in the position of a float or bucket. This movement causes a valve to open and close. Several mechanical trap designs are based on this principle, including ball float, float and lever, inverted bucket, open bucket and float and thermostatic traps (Figure 1).

**Thermodynamic traps.** Thermodynamic traps operate according to changes in fluid dynamics, using the



**FIGURE 1.** This cutaway view shows the internal components of a float-and-thermostatic steam trap

difference in kinetic energy (velocity) between condensate and live steam to operate a valve. The disc trap is the most common thermodynamic trap, but piston or impulse traps are sometimes used.

### Steam trap failure modes

When steam traps fail, it is usually in one of two ways: by leaking live steam or by failing to discharge condensate, either partially or fully.

**Hot-leaking failures.** Steam traps can develop leaks if dirt prevents the valve from fully closing. This reduces the efficiency and effectiveness of the steam system.

**Cold-blocked low-temperature failures.** If the valve fails to open, condensate can back-up into steam headers, resulting in wet steam and waterhammer. In process heating applications, a backup of condensate can cause the heating temperature to drop. This, in turn, can affect product quality.

**Condensate impurities.** Often, a significant portion of the steam condensate is recovered and returned to the boilers. Depending on the plant processes the steam serves, the condensate may contain impurities that include acidic compounds, organic compounds or mineral salts. These impurities can cause corrosion and failure of condensate-return piping and equipment, and they can potentially result in steam-generator corrosion and fouling. ■

### References

1. Department of Energy, Energy Efficiency & Renewable Energy Office, "Improving Steam System Performance: A Sourcebook for Industry, 2nd ed.," U.S. Department of Energy, 2012.
2. International Organization for Standardization, Automatic Steam Traps, ISO 6704:1982, [www.iso.org](http://www.iso.org).
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# Methods for Conceptual Capital-Cost Estimation

Conceptual capital-cost estimates are important for assessing the economic viability of proposed projects, but their usefulness depends on understanding how to appropriately apply the estimates

Capital cost estimates are a crucial step in order to make prudent decisions regarding any development project. Specifically, the economic viability of a development project must be sufficiently supported in order to move forward in the planning process. In the early phases of a development project, cost engineers are often engaged in developing conceptual capital-cost estimates for various types of industrial assets, including full chemical plants, production units, or even individual pieces of equipment. A major hurdle cost engineers can encounter comes when seeking to identify facilities or production units that are similar to the proposed project to serve as benchmarks or pricing reference points. Even when other existing facilities or production units are similar in many aspects, it is very common that the facility or production unit being considered for development differs materially in technology, capacity, location or time of construction. In such instances, an understanding of how to appropriately apply conceptual capital-cost estimating methods is critical.

This article briefly discusses various conceptual capital-cost estimating methods. It then presents a detailed discussion and example on one method for conceptual capital-cost estimating: the cost-to-capacity method, also commonly referred to as the capacity-factored estimating technique. Further, the appropriate application of scale factors utilized in the cost-to-capacity method is presented, along with applicable methodology for scale-factor derivations. Scale factors are also commonly referred to as scaling exponents, scaleup exponents, cost-capacity factors, cost-to-capacity factors and capacity factors.

## Conceptual cost-estimating methods

As identified by the Association for the Advancement of Cost Engineering (AACE International; Morgantown, W.Va.; [www.aacei.org](http://www.aacei.org)), there are five classes of cost estimates, Class 1 through Class 5. A Class 1 cost estimate is the most detailed and is based on a fully defined project scope, while a Class 4 or Class 5 estimate is more conceptual in nature and is based on more limited information and a project scope that is not fully defined [1, 2, 3].

There are multiple commonly utilized conceptual capital-cost estimating methods which would be considered a Class 4 or Class 5 estimate, including but not limited to, the following [4]:

### **Cost-to-capacity estimating method (also referred to as capacity factored method).**

Historical or current capital cost data for a similar project, but with a different capacity, is utilized with a non-linear scaling exponent as the primary basis for the cost estimate of the proposed project.

### **End-product units estimating method.**

Historical capital cost data for similar projects are utilized in conjunction with units of capacity to apply a linear relationship as the primary basis for the estimate of a proposed project.

### **Physical dimensions estimating method.**

Historical capital cost data for similar projects are utilized in conjunction with physical dimensions to apply a linear relationship as the primary basis for the estimate of a proposed project.

**Analogy estimating method.** Historical capital cost data for similar projects with similar capacities are utilized as the primary basis for the estimate of a proposed project.

**Expert judgment estimating method.**

**Clayton Baumann and Chris Rigo**  
evcValuation LLC

## IN BRIEF

CONCEPTUAL COST-ESTIMATING METHODS

COST-TO-CAPACITY METHODOLOGY

APPLICATION CONSIDERATIONS

COST-TO-CAPACITY EXAMPLE

SCALE-FACTOR DERIVATION METHOD

SCALE-FACTOR DERIVATION EXAMPLE

SCALE-FACTOR CONSIDERATIONS

Primarily utilized when there is no reasonably similar project for comparison or available capital costs, the judgment of subject matter experts is used as the primary basis for the estimate of the proposed project.

### Cost-to-capacity methodology

Among the previously presented conceptual capital-cost estimating methods, the cost-to-capacity method is one of the most utilized and easiest to apply. Yet, the method is often not fully understood and is commonly applied in inappropriate and inconsistent ways in conceptual cost-estimating analyses.

The cost-to-capacity concept was originally developed in 1947 by Roger Williams Jr. to develop equipment cost estimates. In 1950, C.H. Chilton expanded the concept's application to estimate total chemical plant costs [3, 5].

The fundamental concept behind the cost-to-capacity method is that the costs of similar facilities, production units, or pieces of equipment with different capacities vary nonlinearly. More specifically, cost is a function of capacity raised to an exponent or scale factor [3, 6] (Equation (1)).

$$C_2/C_1 = (Q_2/Q_1)^X \quad (1)$$

$C_2$  = Unknown capital cost of proposed facility, with capacity  $Q_2$

$C_1$  = Known cost of existing facility, with capacity  $Q_1$

$Q_2$  = Known capacity of proposed facility

$Q_1$  = Known capacity of existing facility

$X$  = Scale factor for existing and proposed facilities

The scale factor in the above equation accounts for the nonlinear relationship and introduces the concept of economies of scale, where, as a facility becomes larger, the incremental cost is reduced for each additional unit of capacity [3, 7]. However, not all facilities, production units, or pieces of equipment actually experience economies of scale related to capital costs. A scale factor of less than 1 indicates that econo-

mies of scale exist and the incremental cost of the next added unit of capacity will be less expensive than the previous unit of capacity. When the scale factor is greater than 1, economies of scale do not exist; rather, dis-economies of scale are at play, and the incremental cost becomes more expensive for every added unit of capacity. A scale factor of exactly 1 indicates that a linear relationship exists and there is no change in the incremental cost per unit of added capacity [3, 8]. A scale factor of 1 also indicates that it is just as economically feasible to build two small facilities as one large facility with the same capacity [3, 4].

### Application considerations

One of the main advantages of the cost-to-capacity method is its relatively easy application. It can be applied to quickly develop reasonable order-of-magnitude capital cost estimates. Potentially even more useful is its capacity to allow sensitivity analyses to be quickly performed when high degrees of accuracy are not required [3, 4]. However, there are a number of considerations that must be addressed prior to applying the cost-to-capacity method [3].

To obtain reasonable results, the technology of the development facility should be the same as, or very close to, that of the existing facility with a known capital cost. Likewise, the scale factor that is applied must appropriately reflect both the technology of the existing facility and the development facility. As will subsequently be discussed in more detail, the scale factor that is applied should also be specifically applicable to the range of capacities for the specific technology of existing facility and development facility [3].

In addition to technology, the cost engineer must consider the configuration of the existing and development facility, their location, and any unique design and site characteristics of each. Differences in location would almost always require the application of a locational cost adjustment factor. There are various sources that publish location-based indices that can be used for making

location adjustments, including the following: Compass International Estimating Yearbooks, Marshall & Swift (M&S) Valuation Service, RSMeans Cost Manuals, Engineering News-Record and U.S. Department of Defense publications. To develop a location adjustment factor, the same basic equation that is subsequently presented for making time adjustments is applicable. Likewise, different configurations or unique design or site characteristics of the existing or development facility would require a cost adjustment prior to completing the cost-to-capacity analysis. Significant differences between the existing and development facility in any of the aforementioned areas can yield nonmeaningful capital cost estimates [3, 7].

Lastly, prior to applying the cost-to-capacity method, the known capital costs of the existing facility that have a specified reference year must be appropriately adjusted for inflation in order to develop a reliable cost estimate for the proposed facility. For example, it may be required to develop a capital cost estimate for a proposed chemical facility in current dollars but the known capital costs of the similar existing reference facility are in 2020 dollars. In general terms, to appropriately account for the effects of cost inflation, the known capital costs for the existing facility must be escalated using appropriate cost indices applicable to the technology in question [3, 7]. In this example, the known capital costs for the existing facility must be multiplied by a ratio of the current year index and the 2020 index [3, 6].

Equation (2) illustrates the general relationship:

$$C_2 = C_1 (Index_2/Index_1) \quad (2)$$

$C_2$  = Estimated cost of proposed facility in applicable year

$C_1$  = Known capital cost of existing facility in reference year

$Index_2$  = Proposed facility estimated year cost index

$Index_1$  = Existing facility reference year cost index

When using cost indices to escalate known capital costs, there are some nuances of which to be aware. The older the known capital costs are, the greater potential there is to have diminished accuracy in the capital cost estimate of the proposed facility. Thus, known capital costs for existing facilities that are escalated for inflation using the previously presented equation need to be analyzed to determine whether they are still appropriate and relevant. When estimating capital costs for a development facility, the use of known capital costs for existing facilities that are as current as possible will typically yield more meaningful results [3, 6].

Some commonly used, reliable cost indices that can be applied in escalating known capital costs for existing facilities include the following: Handy-Whitman Index of Public Utility Construction Costs, Engineering News-Record (ENR) Construction Cost Index, Nelson-Farrar Refinery Cost Index, IHS Downstream Capital Cost Index (DCCI), the Chemical Engineering Plant Cost Index® (CEPCI) and the M&S Cost Index [3].

### Cost-to-capacity example

A simple application example of the cost-to-capacity method is given below in order to better illustrate the previously discussed concepts and methodologies.

A conceptual capital cost estimate is needed for the proposed development of a 1,500 ton/d ammonia plant near Des Moines, Iowa as of a current date. There are known capital costs for a similar plant of the same technology located near Houston, Texas with a capacity of approximately 1,000 ton/d, which had construction completed in January 2022. The total capital cost of the existing plant in January 2022 dollars was approximately \$715,000,000. It is concluded that because the existing plant is very similar to the proposed plant and employs the same process technology, no cost adjustment is required for unique design characteristics. However, due to the fact that proposed facility is located in a different region than the existing facility, a location adjustment is required. Additionally, an adjustment must be made to the known capital costs in January 2022 dollars for time and inflation in order to get a cost estimate as of a current date. Lastly, an adjustment must be made for the difference in capacities of the existing and proposed facilities by utilizing the cost-to-capacity method.

First, the known capital costs for the existing ammonia plant located near Houston must be adjusted to get to an estimate of the capital costs if had been constructed near Des Moines. A location index applicable to the chemical industry indicates a location index of 117.0 for Houston, Texas and a location index of 128.0 for Des Moines, Iowa. Applying the two indices in a formula similar to the time adjustment formula is shown below:

*Existing Plant Capital Cost Adjusted to Des Moines, Iowa* = \$715,000,000 × (128.0/117.0)



For details visit [adlinks.chemengonline.com/86470-04](https://adlinks.chemengonline.com/86470-04)

Existing Plant Capital Cost Adjusted to Des Moines, Iowa = \$782,000,000 (rounded)

Next, the location-adjusted capital costs, which are still in January 2022 dollars, must be converted to current dollars. An applicable cost index for the chemical industry indicates a January 2022 index value of 1,085.0 and a current date index value of 1,180.0. Applying the two indices in the previously presented formula is presented below:

Location Adjusted Capital Cost Escalated to Current Cost = \$782,000,000  $\times$  (1,180.0/1,085.0)

Location Adjusted Capital Cost Escalated to Current Cost = \$850,000,000 (rounded)

Lastly, the location-adjusted, time-escalated cost must be scaled to account for the difference in capacities between the proposed and existing ammonia plants. A credible source indicates that an appropriate scale factor to apply in cost estimates for an ammonia plant is 0.78. The previously introduced equation for the cost-to-capacity method can now be mathematically manipulated and solved as follows:

Location and Scale Adjusted Current Cost Estimate = \$850,000,000

$$\times [(1,500 \text{ ton/d})/(1,000 \text{ ton/d})]^{0.78}$$

Location and Scale Adjusted Current Cost Estimate = \$1,166,000,000 (rounded)

As shown in the above cost estimate example, a capacity increase of 1.5 times results in a capital cost increase of approximately 1.37 times. This expresses the previously introduced concept of economies of scale inherent in applying a scale factor of less than 1 [3].

### Scale-factor derivation method

One of most crucial components when applying the cost-to-capacity method is an appropriate scale factor. The previously mentioned study performed by C.H. Chilton in 1950 derived a common scale factor for chemical facilities of approximately 0.6, which led to the cost-to-capacity method being referred to early on as the “six-tenths rule” [3, 8]. Since the Chilton study, many other sources have published scale factors for various industrial facilities and equipment of certain technologies. However, the majority of these scale factors are not published with supporting industry data and derivations [3].

The methodology for deriving a scale factor is similar in nature to the cost-to-capacity method equation as previously presented. If cost and capacity data are known for different

Capacity (hp)	Cost (\$)	Cost per capacity, (\$/hp)
1.0	956.51	956.51
1.5	1,184.13	789.42
2.0	1,279.37	639.69
3.0	1,396.83	465.61
4.0	1,530.16	382.54
5.0	2,083.49	416.61
7.5	2,381.98	317.60
10.0	2,518.44	251.84
15.0	3,492.73	232.85
20.0	4,197.68	209.88

facilities, production units, or prices of equipment with the same or very similar technology and design, then a scale factor can be derived. The previously presented equation for the cost-to-capacity method can easily be transformed by applying natural logarithms (ln) to the cost and capacity data on both sides of the equation to develop a linear relationship. It can then be further manipulated to solve for the non-linear scale factor,  $x$ . Equations (3) through (6) show this relationship [3].

$$C_2/C_1 = (Q_2/Q_1)^x \quad (3)$$

$$\ln(C_2/C_1) = \ln(Q_2/Q_1)^x \quad (4)$$

$$\ln(C_2/C_1) = x \times \ln(Q_2/Q_1) \quad (5)$$

$$[\ln(C_2/C_1)] / [\ln(Q_2/Q_1)] = x \quad (6)$$

The above relationship outlines the basic concept behind the development of a linear relationship and the derivation of a scale factor. However, in order to derive a more accurate scale factor for a particular facility, production unit, or piece of equipment with a certain technology, an entire set of capital cost and capacity data must be available and analyzed. To accomplish this, natural logarithms can be applied to an entire set of cost and capacity data and then graphed. A linear regression analysis of the natural logarithm of the cost and capacity data can then be performed using graphing computer software. The resultant linear regression line slope is the representative scale factor for that particular type of facility with a specific technology [3, 8].

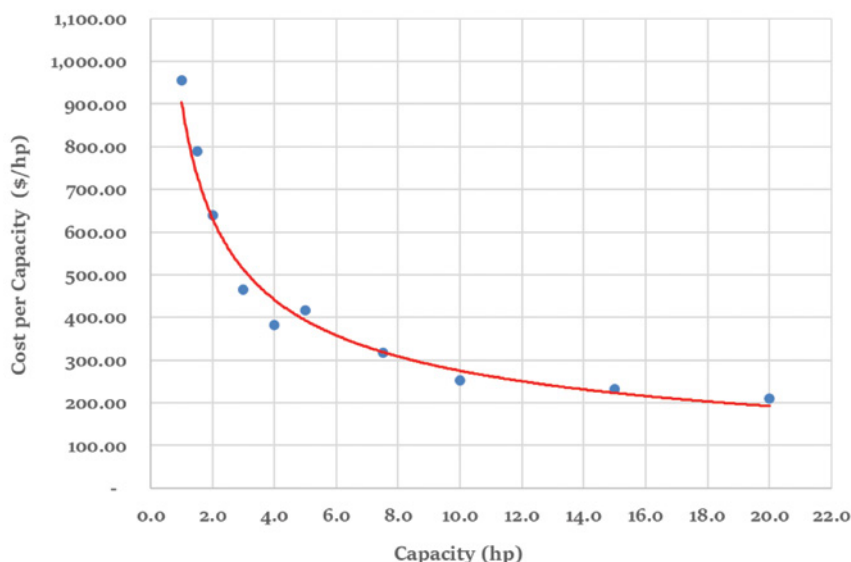
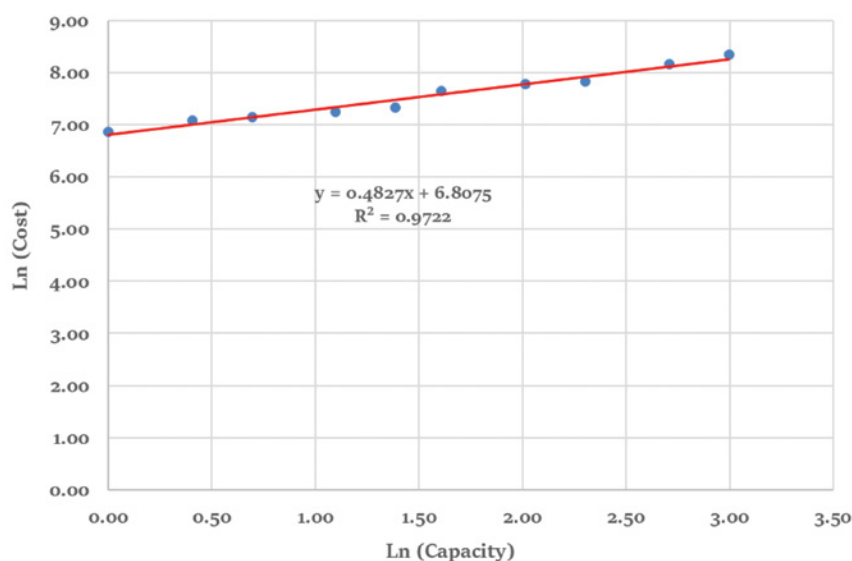


FIGURE 1. The graph shows the declining cost per horsepower of capacity for a horizontal centrifugal pump



**FIGURE 2.** A linear regression equation, using natural logarithms, is shown for the data from Figure 2. The slope of the line represents the scale factor for the given data

It is important that the cost and capacity data that are gathered and analyzed in the linear regression analysis are consistent with respect to design parameters, such as technology, configuration, location and unique site characteristics. These are similar to the considerations of the cost-to-capacity method, as previously stated [3].

### Scale-factor derivation example

An example is best to illustrate the derivation of a scale factor using regression analysis. Table 1 presents the capacity and associated cost and cost per horsepower (hp) for different capacities of horizontal centrifugal pumps in current dollars. The data set is for the off-the-shelf cost for horizontal centrifugal pumps from the same manufac-

turer and is concluded to be an acceptable data set because it has consistent cost information. When deriving a scale factor for an entire facility or production unit, the most reliable data set is one that is consistent and has the same or very similar basic manufacturer designs, location basis, technology and configuration. If there are variations in the costs that make up the data set in relation to any of these attributes, certain adjustments may need to be made prior to performing the scale factor derivation. It should be noted that the methodology presented in the following example is universal and can apply to any data set for known capital costs and capacities for entire facilities, production units, or pieces of equipment.

The data in Table 1 illustrate a declining trend in the cost per hp of capacity as the size of the horizontal centrifugal pump increases. This demonstrates the concept of economies of scale that exist as capacity increases. Figure 1 provides a visual depiction of the declining cost per horsepower of capacity.

The relationship of economies of scale that exists for horizontal centrifugal pumps is what is captured when deriving the scale factor for the above data set. As previously described, in order to derive a scale factor from the above data set, natural logarithms are applied to both the cost and capacity data and then graphed. A linear regression analysis is then performed on the natural logarithm of the total cost and capacity to derive a linear regression equation. Figure 2 shows a graph of the natural logarithm of the cost and capacity data from Table 1, along with the resultant linear regression equation [3].

Per the linear regression equation shown in Figure 2, the slope of the line is 0.4827. As previously discussed, this slope is representative of the scale factor for the given set of cost and capacity data analyzed. Thus, the derived scale factor for horizontal centrifugal pump for the range of capacities analyzed is concluded to be approximately 0.48, rounded.

**TABLE 2. CAPACITY RATIO ( $Q_2/Q_1$ )**

Scale factor applied	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
0.20	-18%	-29%	-37%	-42%	-47%	-50%	-53%	-55%
0.25	-17%	-27%	-34%	-39%	-43%	-46%	-49%	-52%
0.30	-15%	-24%	-31%	-36%	-39%	-43%	-45%	-47%
0.35	-13%	-22%	-27%	-32%	-35%	-38%	-41%	-43%
0.40	-11%	-19%	-24%	-28%	-31%	-34%	-36%	-38%
0.45	-10%	-16%	-20%	-24%	-27%	-29%	-31%	-33%
0.50	-8%	-13%	-17%	-20%	-22%	-24%	-26%	-28%
0.55	-6%	-10%	-13%	-15%	-17%	-19%	-20%	-21%
0.60	-4%	-7%	-9%	-10%	-12%	-13%	-14%	-15%
0.65	-2%	-3%	-4%	-5%	-6%	-7%	-7%	-8%
0.70	0%	0%	0%	0%	0%	0%	0%	0%
0.75	2%	4%	5%	6%	6%	7%	8%	8%
0.80	4%	7%	10%	12%	13%	15%	16%	17%
0.85	6%	11%	15%	18%	21%	23%	25%	27%
0.90	8%	15%	20%	25%	28%	32%	35%	38%
0.95	11%	19%	26%	32%	37%	41%	46%	50%
1.00	13%	23%	32%	39%	46%	52%	57%	62%
1.05	15%	27%	38%	47%	55%	62%	69%	76%
1.10	18%	32%	44%	55%	65%	74%	83%	90%

$R_2$  values calculated in linear regression analyses are indicators of how closely a linear regression line approximates a given set of data. The closer the  $R_2$  value is to 1, the better the regression line estimates the data set. By visual inspection, the linear regression equation appears to closely match the set of data. Furthermore, the  $R_2$  shown in Figure 2 is 0.9722, indicating that the linear regression equation is a good approximate for the data set [3].

### Scale factor considerations

The previously presented scale-factor derivation for the cost and capacity data for the horizontal centrifugal pump is a simplified example in that one scale factor was derived for a range of horsepower capacities. Depending on the type of technology of the particular facility, production unit, or piece of equipment, the scale factor could increase at certain ranges of capacity due to fixed increases in costs for larger capacities [3, 10]. In many cases, if a set of cost and capacity data are broken down into subsets and a scale-factor derivation is performed, the resultant scale factors for the larger-capacity subsets could be greater than the smaller capacity subsets. Thus, caution should be used when deriving a single scale factor based on broad ranges of capacities for a particular facility, production unit, or piece of equipment. Understanding that scale factors may vary over ranges of capacities should cause a level of caution to be taken when applying a single scale factor in cost-to-capacity analyses for a broad range of facility, production unit, or equipment capacity. Utilizing a scale factor that is not appropriate for a given range of capacities will lead to less reliable conceptual capital cost estimate results [3].

For illustrative purposes, assume a conceptual capital cost estimate is undertaken for a development project and the appropriate scale factor to apply for the given facility of a certain technology and capacity is 0.70. Table 2 presents the potential percent error inherent in the

capital cost estimate if the scale factor applied in the analysis deviates from 0.70.

Table 2 shows that the use of an inappropriate scale factor can introduce significant error. Thus, it is critical that the scale factor applied in the cost-to-capacity method should be supported by publications or derivations and should apply to the technology and range of capacities applicable to the capital cost estimate in order to yield a reliable capital cost estimation [11].

### Concluding remarks

Conceptual capital-cost estimates can be useful tools when making decisions early on in the planning process for a development project when only a limited project scope exists. In order to arrive at reasonable capital cost estimates, cost engineers must be aware of the various conceptual cost-estimating methods that exist and certain considerations associated with each. The cost-to-capacity method is one tool that can allow cost engineers to develop conceptual capital-cost estimates for entire facilities, production units, or pieces of equipment based on known capital costs for similar assets with different capacities. While mathematically, the cost-to-capacity method is fairly simplistic, it must be applied in a consistent and appropriate manner in order to produce meaningful results. Analyzing and utilizing cost data for facilities, production units, or equipment that are not adequately similar to the subject of the cost estimate, or applying a scale factor that is arbitrary or not appropriate, can result in a significant under- or overstatement of the capital cost estimate. However, when applied appropriately, the cost-to-capacity method can yield fairly quick and reliable conceptual capital-cost estimates, which can be critical in determining the ultimate economic feasibility of a development project. ■

*Edited by Scott Jenkins*

### Acknowledgment

Graphs supplied by evcValuation

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# Cost Engineering with Previously Owned Process Equipment

Previously used process equipment can offer significant cost advantages in capital construction projects, but there are important questions to consider before pursuing pre-owned equipment

Many misconceptions persist in the marketplace about second-hand equipment. Companies worry that previously owned equipment may not be in reliable condition, leading to potential breakdowns or run-away maintenance costs that evaporate cost savings. They fear used equipment won't match the performance or efficiency of new models, especially if technological advances have been made. And still others believe that used equipment may not integrate smoothly with current systems or may lack modern features, requiring costly modifications or leading to inefficiencies. Put another way, the main question companies grapple with is this: Are the cost and lead time savings gained with used equipment really worth the potential downside?

While these concerns certainly are understandable, the reality is that these risks can be effectively mitigated when purchasing from a trusted supplier. There is plenty of "bang for the buck" to be realized when buying used plants, systems and equipment. This article discusses some ways to alleviate concerns over used equipment, and outlines the questions that should be asked before purchasing used process equipment.

## Cost and time savings

When manufacturers find the right fit for used equipment, the large savings in capital cost and lead time savings often come as a welcome surprise. In the author's experience, quality secondhand equipment can save companies 50% on cost and 90% on delivery times. For companies that buy complete pre-owned systems or plants, the savings can reach 70% on cost and at least 50% lead time for engineering and equip-



**FIGURE 1.** Potential buyers of pre-owned equipment can inspect the pieces and conduct tests prior to finalizing the sale

ment supply. These savings often justify natural concerns about purchasing assets that were not custom-designed for the application, but will do the job comparably at a fraction of the cost and lead time.

Used equipment may come with imperfect specifications, but it arrives at the right price and at the right time. In today's competitive global market, time and money are two terrible things to waste. Why should manufacturers strive for the unattainable goal of engineering perfection in designing manufacturing plants when they can aim for a more reasonable target that can be in service on a shorter schedule and for less cost?

## Testing and compatibility

In many cases, historical operating records and maintenance documentation can be provided when purchasing the equipment to get a better understanding of maintenance needs. Buyers can inspect the equipment prior to purchase, which may include conducting tests, such as thickness tests, run tests and hydrostatic-pressure tests to

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## IN BRIEF

COST AND TIME SAVINGS

TESTING AND  
COMPATIBILITY

ASSESSING PRE-OWNED  
EQUIPMENT

QUALITY, RELIABILITY  
AND SERVICE LIFE

INDUSTRY EXAMPLES

ENVIRONMENTAL IMPACT

ensure serviceability (Figure 1). Regardless, there are still general preventative maintenance recommendations, such as lubrication, bearing and seal replacement that would be advisable in certain situations.

When it comes to integration with existing systems, used equipment vendors work closely with clients and, in some cases, their external consultants to assess compatibility. If needed, vendors can assist with arranging third-party customization or retrofitting solutions. This ensures the equipment fits seamlessly into operations, avoiding costly disruptions, inefficiencies or extended downtime. Often, upgrades or modern features can be added without significant cost or delay to improve efficiency, allowing companies to benefit from the latest innovations on a tighter budget. For example, updated controls and sensors can be added during installation in a buyer's facility to improve reliability and efficiency using industrial internet of things (IIoT)-enabled devices and systems.

Ultimately, purchasing used process systems or equipment from a reputable provider is a strategic decision that must satisfy the cost and time benefits — without compromising on performance to meet the commercial need.

### Assessing pre-owned equipment

When assessing secondhand equipment for potential purchase, a number of important cost-engineering questions should be asked. Below are five key questions to ask that will help to mitigate the perceived cost-engineering risks associated with

secondhand equipment:

#### **Which equipment specifications can be flexible?**

It's natural for manufacturers to focus their investments on optimizing production, product quality, safety and adherence to the bottom line when asked to navigate growth on tight budgets and timelines. Often, the default for project engineers is to define tight specifications and for the team's procurement personnel to send those specs to a variety of equipment manufacturers. The result, more often than not for companies needing to add capacity, is to select the best offer without considering used or secondhand options.

When selecting good used assets, there is often not an exact match for your specific requirement. Understanding your "must have" attributes is critical to being successful. For example, if your project scope specifies Hastelloy material of construction, would it be possible to utilize glass-lined steel to accomplish corrosion resistance while saving significant capital?

#### **What is the maintenance history of the equipment (or plant)?**

Generally, the fabrication documents, maintenance documentation, operating records and previous-use information are available when purchasing used equipment from its prior operator or a from reputable source.

For current good manufacturing practices (cGMP) applications, validation and cleaning documents are made available to ensure you can re-validate and place the equipment back into service in your process. These records will give a new owner the confidence that the assets can perform as intended with the proper continued care and maintenance (Figure 2).

#### **What visual or mechanical inspections can be done to ascertain condition?**

When purchasing equipment or a plant from the original owner or a well-regarded source, the maintenance records can often tell the entire story about the



**FIGURE 3.** A thorough cost-benefit analysis of secondhand plants and equipment can quantify the potential cost savings

equipment or plant, even if the equipment has stopped operation before you can see it. Certain buyers may find more comfort in being able to perform their own tests or inspections — such as ultrasonic thickness testing on pressure vessels, hydrostatic pressure tests, motor megger testing, eddy-current testing of heat exchangers and others. In most situations, visual inspections are sufficient.

#### **What is the reputation and quality standard of the used equipment dealer under consideration?**

It is very understandable that used equipment (including used automobiles) may not have the best reputation for high quality and reliability. Buyers are encouraged to carefully choose partners that offer a high level of service — ask for references, testimonials or case studies of other companies that have successfully integrated similar equipment into their manufacturing ecosystems. At the end of the day, professional used-equipment dealers want satisfied, repeat customers, and will do their best to ensure that unfortunate and unforeseen circumstances are resolved amicably. The world might be a big place in some ways, but it's smaller than ever in other ways and bad news can travel fast.

#### **What are the cost benefits of used compared to new equipment?**

This may seem like an obvious question, "doing the math" can make the value proposition of used equipment clear. The author's extensive experience in the industry focusing on qualitative improvements of used equipment, along with thousands of discussions with people across dozens of industries, has shown that running the cost-benefit num-



**FIGURE 2.** There are five considerations that will help mitigate the perceived risks of secondhand equipment, including reviewing the maintenance history of the equipment or plant

bers can solidify the potential time and cost savings (Figure 3). A host of considerations are important in quantifying the costs and benefits, among them: savings in initial capital outlay compared to buying new equipment; potential maintenance and adaptation costs; and in some cases, the energy efficiency of used equipment versus newer models.

### Quality, reliability and service life

A major reason why engineers might hesitate to specify used equipment is the misconception that it is inherently inferior in quality, reliability or service life compared to new equipment. However, most types of industrial equipment are robustly designed to last for many decades with proper use, inspection and maintenance. This is another reason that maintenance histories, when available, are so useful.

Often, used equipment is available on the market after only short periods of use, or even no use at all, due to changing or canceled projects. Used equipment can be inspected to determine wear and damage, and components reconditioned and updated with modern controls and safety features at a lower cost than purchasing new. In many cases, used equipment can be just as reliable as new equipment, with the added benefit that its performance history is often available. Engineers

can review data from previous operations to gain insights into how the equipment has performed over time. Access to such data are not an option when purchasing new.

The key to successfully integrating used equipment into most capital projects lies in design flexibility (Figure 4). Engineers can specify slightly broader operating ranges, allowing for minor deviations in parameters, such as temperature, pressure or flowrates. In many processes, especially those that are noncritical or don't require extreme precision, these deviations do not materially affect the overall performance or production outcome.

Process engineers and chemical engineers are trained to ensure that systems function within specific design limits, and this often leads to conservative choices. However, by recalculating the operating ranges of a process to accommodate used equipment, engineers can provide their companies with significant cost savings without negatively affecting the production process.

In some cases, larger equipment could be procured to accommodate growth. Used equipment that was designed for higher-capacity operations, more features, or built with higher grades of metals could easily fit into a system operating at lower thresholds. This inherent flexibility allows companies to leverage pre-owned equipment that might not have been an obvious choice initially, but that functions perfectly within the specific context of their operations and is "future-proofed" for continued growth or a different product slate. For example, having a larger Hastelloy agitated nutsche filter dryer in an active pharmaceutical ingredient (API) pharmaceutical plant, where a smaller 316 stainless-steel vessel is required, can give a manufacturer the future potential of processing more acidic materials.

Another factor to consider is that most batch-type process equipment technologies used today have not had significant design and efficiency changes since nearly a century ago, reducing their obsolescence. For example, heat exchanger and reactor designs used in process manu-

facturing today have been the same for nearly a century. Only incremental improvements have changed those types of equipment, and those changes have arrived mostly through improved controls, sensors and instruments.

The other truth about process equipment is that with proper operation and maintenance, high-quality process equipment is built to operate well beyond its stated useful life — even when it has been running full time.

From petroleum refineries built in the first half of the last century, through specialty chemical and pharmaceutical assets dating to the 1970s, it has been proven that most static and rotating equipment, with proper care, can far outlive their designed 20- to 30-year operating life.

### Industry examples

The author's company has a long track record of case studies from around the globe that illustrate the potential cost and lead-time benefits that can be realized with pre-owned assets. Here are two examples of cost-engineering cases using pre-owned equipment:

The first involves the sale of a world-class ammonia plant from a canceled project, in which all the engineering and equipment fabrication was completed at the time of the project cancellation. As unlikely as it seems, brand new, unused equipment had either been delivered to the plant site or was awaiting shipment from vendor shops. None had yet been put into operation.

The client was able to reformat the site-specific engineering to meet its site conditions and install the plant on the other side of the world. This client is now one of the leading producers in its space in its country.

The final price tag for this project was less than half of the original project cost, which had initially been proposed as a new greenfield build budgeted at \$600 million. It also should be noted that the timeline of the project from start to finish was under three years, during the COVID-19 pandemic, whereas the build-new projection was five years.

In a second example, at the equip-



**FIGURE 4.** The key to successfully integrating used equipment into capital projects is design flexibility



**FIGURE 5.** Choosing good used equipment can have impacts that go beyond cost, including in areas related to sustainability and community impact

ment scale, a U.S.-based custom-manufacturing customer had an urgent project for a specialty chemical. The company could not wait the quoted 40 weeks for a brand-new glass-lined reactor and their client was unwilling to commit to a long-term supply agreement over which the client could amortize the high cost of new equipment.

The customer purchased a secondhand glass-lined reactor that had been pressure tested, spark-tested, gearbox-rebuilt and repainted at 50% of the cost for a new reactor.



goals like sustainability, efficiency and community impact (Figure 5). Choosing good used equipment can play a crucial role in achieving these objectives, especially for businesses aiming to minimize their environmental footprint and foster economic regeneration. This increased awareness of the circular economy has become a powerful motivator in today's market. More and more companies are aiming to reduce waste and extend the lifecycle of their industrial assets.

What might be the impact of employing pre-owned equipment on sustainability? Consider the following:

- According to the John D. and Ellen T. MacArthur Foundation (Chicago, Ill.; [www.macfound.org](http://www.macfound.org)), a global charitable organization that funds a variety of projects on sustainability, climate, social justice and others, the circular economy could create a \$4.5 trillion economic opportunity by 2030. The foundation's approach favors keeping materials in use significantly longer than in previous generations to reduce the need for raw-material extraction, manufacturing and transportation – all of which are energy-intensive processes.

- Research published by the International Energy Agency (IEA; Paris, France; [www.iea.org](http://www.iea.org)) indicates that the manufacturing sector is responsible for nearly 24% of direct CO<sub>2</sub> emissions from the global energy system. By targeting good, used systems, companies can achieve their expansion goals while minimizing their carbon footprint. For example, the reuse of equipment in capital projects can reduce carbon emissions by up to 70% compared

The time to delivery was just three weeks after the order, allowing them to win the contract and deliver product ahead of schedule and with reduced capital expense.

### Environmental impact

Capital cost is obviously only one concern when cost engineers make the new-versus-used evaluation. Increasingly, companies are looking beyond price tags and leaning into broader

to sourcing new equipment.

- A study by the American Chemistry Council (ACC; Washington, D.C.; [www.americanchemistry.com](http://www.americanchemistry.com)) found that for every direct job in the chemical industry, 7.5 jobs are supported indirectly in the broader economy. By investing in used equipment, companies can quickly restore jobs that were lost when plants were idled, providing a boost to local employment and economic stability.

The “reduce-reuse-recycle” approach has become increasingly important in the chemical product marketplace, driven by rising consumer expectations and regulatory pressures. The European Union, for example, has set ambitious circular economy targets as part of its Green Deal legislative package, aiming for a 55% reduction in greenhouse gas emissions by 2030.

This shift to sustainable practices is not just about corporate responsibility – it is also about economic sense. Reducing, reusing and recycling save companies money and deliver a power driver to local economies.

By focusing on these benefits – sustainability, community revitalization and cost savings – companies can make smarter decisions about their capital projects. And when the time comes to add capacity, considering used equipment is more than just an economic choice for cost engineers. It's a commitment to a more sustainable future. ■

*Edited by Scott Jenkins*

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All photos appear courtesy of IPP

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# Electrochemical Processes for the Chemical Industry

The push toward decarbonization is driving an increased interest in electrochemical processes. Here, the authors share their experience in industrializing these processes

The field of electrochemistry offers a disruptive methodology to revolutionize the chemical process industries (CPI) by electrifying processes. However, scaling up and implementing a new electrochemical synthesis poses challenges that can best be overcome through a combination of academic research and industrial expertise. This article discusses the potential of electrochemistry as a tool to revolutionize and decarbonize the CPI, while also examining the obstacles and unique considerations involved when implementing it in an industrial setting. Examples are given to demonstrate the versatility and exceptional performance of electrosynthesis. Having collaborated for many years between academia and industry, the authors share experiences gained from industrializing such timely methods, and aim to eliminate any concerns readers may have about scaling new electrochemical processes.

Within the CPI, lowering the carbon footprint and increasing efficiency, in line with so-called “green” processes, is becoming progressively important. Topics such as the circular economy, recycling and upcycling of raw materials and the energy transition are in focus. Processes must be redesigned in a resource-friendly and sustainable manner

to circumvent the ongoing climate crisis. Disruptive technologies will play a major role in these activities to develop and establish more efficient processes.

## Synthetic conversions

The use of electricity instead of chemical reagents has applications in organic syntheses, purification processes and downstream technology. By application of electricity, electrons can participate directly as reagents. An example of how a classical organic oxidative coupling could be made not only greener but also more economically efficient, by saving several synthetic steps, is the synthesis of non-symmetrical derivatives of 2,2'-biphenol shown in Figure 1.

Thus, a ligand backbone for a catalyst applied in a major chemical process in the production of oil additives, the hydroformylation reaction, was developed by the author's laboratory [1–4]. The electrochemical reaction pathway saves five synthesis steps compared to the classical route and doesn't require leaving groups in order to form the  $C(sp^2)-C(sp^2)$  bond.

A noteworthy illustration of electrochemical synthesis applied to inorganic components is the anodic periodate synthesis. This is a common platform oxidizer

in the chemical industry, which has already been scaled-up to generate several kilograms of product. Outstandingly, this method uses only electricity to synthesize periodate, without the need for external oxidizing agents.

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## IN BRIEF

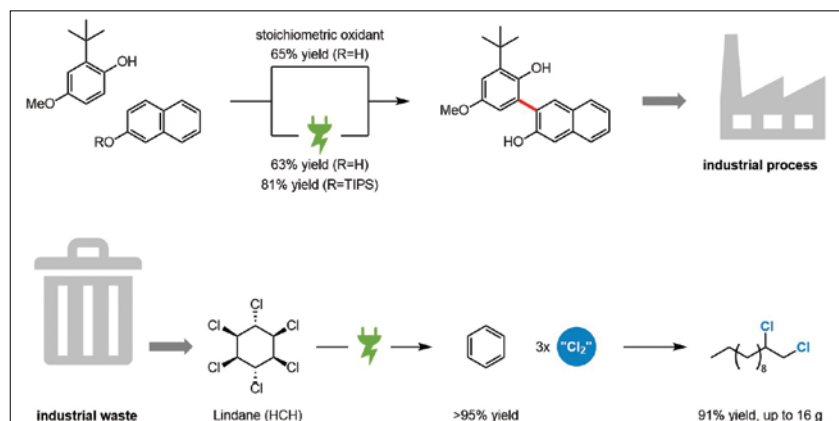
SYNTHETIC  
CONVERSIONS

DOWNSTREAM  
PROCESSING

CHALLENGES

SPECIFIC  
CONSIDERATIONS

SCALING UP: STEP-BY-  
STEP GUIDE



**FIGURE 1.** The reaction pathway for the synthesis of biphenol is an example of an industrially relevant electro-organic synthesis. The HCH upcycling reaction pathway is an example for an electro-organic driven circular economy [3, 4, 10, 11]

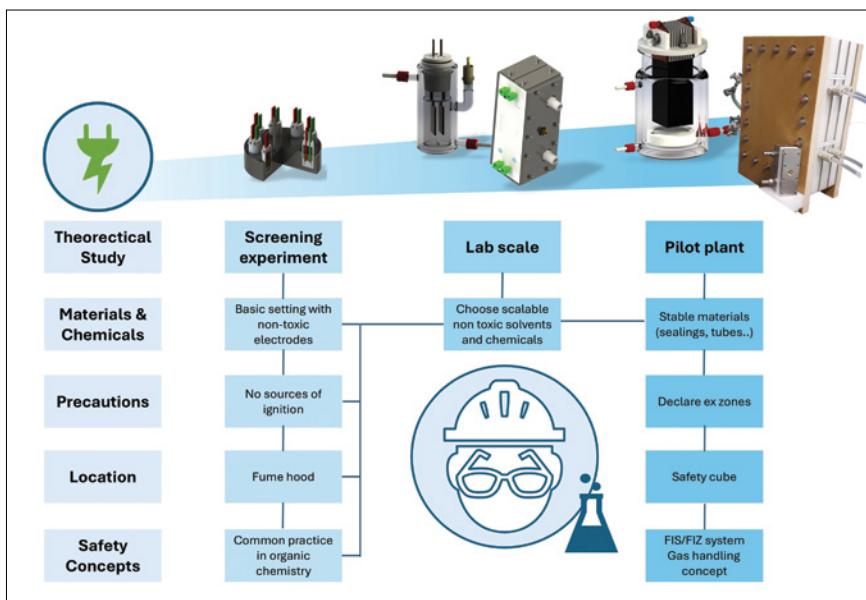


FIGURE 2. Consider safety aspects in the scaling process of an electro-organic synthesis process

Moreover, iodo waste can be fed in, and the complete mineralization of organics results in periodination [5]. This approach exemplifies the resource- and chemical-efficient nature of electrochemical syntheses [5–7].

A method for the oxidative ring opening of cyclic hydrocarbons was also developed to eliminate the need for an oxidizer. By utilizing nickel oxide hydroxide anodes, a process was established for synthesizing substituted adipic acid derivatives from lignin-derived feedstock and was successfully scaled up to over 10 liters [8–9]. These examples epitomize the potential of electrosynthesis to enable conversions that are not only mild, resource-efficient, and sustainable, but also capable of being scaled up to meet industrial requirements.

### Downstream processing

On top of classical synthesis, electrochemistry is also used for downstream processing. Applied electrochemical downstream methods are electrodialysis, wastewater treatment and electrostatic purification. An interesting example in electrochemical waste utilization is the upcycling of chlorinated persistent pesticides. This waste is not readily decomposed by nature and has been put into landfills on a multi-million-ton scale. In order to tackle this

problem, researchers developed an electrosynthesis (e-shuttle) for upcycling this waste, which generated benzene and chlorine equivalents — both base chemicals that are highly relevant for the industry [10]. This example highlights the versatility of electrochemical processes in the search of a sustainable future.

### Challenges

The innovation of electrosynthesis can lead to many approaches for optimizing chemical processes, but also poses challenges. Modern approaches do not focus on electrochemical stand-alone systems, but integrate electrochemical sub-steps as a part of a longer process chain. This enables the gradual implementation of electrochemical innovations in the industrial environment.

One of the biggest challenges when using electrochemistry in the chemical industry is the technical implementation. Unlike chlor-alkali electrolysis, which has been used on a technical scale for decades, most electrochemical syntheses and processes are completely new and have to be designed from scratch. There are almost no commercially available pilot systems for the examples mentioned above, and to the current authors' knowledge, there are no plants on an industrial scale that are commercially available. The lack of availability of these plants requires

## COMMON ELECTROCHEMISTRY MYTHS AND CONCERNS

- 1. Scaling up in electrochemistry is always done by numbering up.** Not true — some methods use different cell setups and special electrode designs
- 2. Electrochemistry has its own distinct language.** Yes, but as in any scaling process, chemists and engineers must bridge their different languages
- 3. Electrochemical equipment will cause sparks or shocks that are dangerous to operators.** Most electrochemical cells operate below 10 V d.c. However, stray current can be a problem in electrochemical plants
- 4. Electrochemistry is expensive.** Although systems are often customized, electrochemical processes can compete economically due to lower carbon dioxide emissions

technical implementation within every company and their workshops, or highly individualized plants from the few available manufacturers (for electrodialysis, for example, Eurodia, MEGA, Fumatec).

It is even more difficult to find suppliers for large-scale plants in the field of organic electrosynthesis. Both options require knowledge of the hurdles and peculiarities of an electrochemical pilot plant and the ability to fix them internally. To dispel fears of implementing electrochemical processes, this article aims to avoid prejudices and typical mistakes from the outset [12–13].

### Specific considerations

So let's dive into the possibilities of electrochemical processes and share with you our experience in scaling up

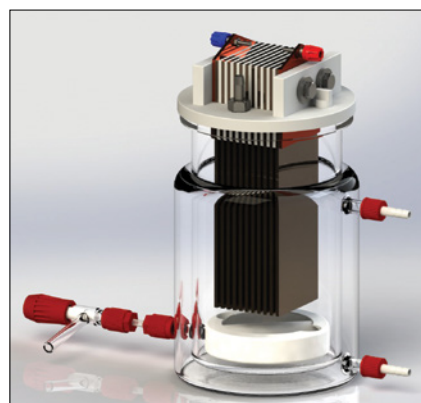


FIGURE 3. A proof of concept is typically started on the laboratory scale



**FIGURE 4.** After proving a concept in the laboratory, the next step in scaleup involves a mini plant like this electrosynthesis pilot plant

these processes. The next sections discuss the most important aspects that differ the most from classical chemical processes. These include: safety, material stability, impurities, suppliers and economics.

**Safety.** The safety of every reaction is of utmost importance in the chemical industry. The same applies to electro-organic reactions, where some peculiarities come into play. In scaling up an electrochemical reaction, several aspects must be considered, which can often be neglected in the laboratory on a screening scale, since working under standard laboratory conditions is sufficient for the safety concept (Figure 2).

The first aspect that distinguishes the electrochemical reaction from standard organic reactions is the most obvious one, namely the use of electricity. On the one hand, this aspect offers the advantage that ending unpredictable reactions is easily ensured by switching off the electricity. However, the use of electricity brings some challenges, especially on the pilot scale. The choice of materials can prevent some problems. For example, the use of stainless-steel pipes should be avoided due to so-called stray current. In addition, it should be ensured that safety signs with warnings of electrical risks, such as “caution electricity,” are visibly displayed.

Another peculiarity in electrochemistry is the emission of gases. Typical

gases formed in an aqueous solution are hydrogen at the cathode and oxygen at the anode. Since these gases can create an explosive atmosphere, especially in a mixture and when enriched, normal safety concepts, such as working in a fume hood and keeping all ignition sources away, are not sufficient at a larger scale. When working at the pilot scale, these gases must be diluted to lower than an explosive level. This can be achieved through complete inertization of the system or flushing concepts. To complete the safety concept and enable operation of the system without continuous monitoring of the flow, so-called flow-indication switch (FIS) shutdowns are used. These ensure that the power is shut off when the air flow decreases. If such a system is not sufficient, so-called explosive zones must be defined in plants. In addition to hydrogen and oxygen, toxic gases such as chlorine can also be emitted. Diluting the gas is not sufficient in this case, and neutralizing the gas is necessary.

Especially in organic electrochemistry, attention is also paid to the use of organic solvents and the use of alkylammonium salts as a supporting electrolyte, which are used in non-polar solvents. Therefore, the chemicals used should be safe in terms of their use in larger quantities (keywords are toxicity and flammability). The use of alkyl-

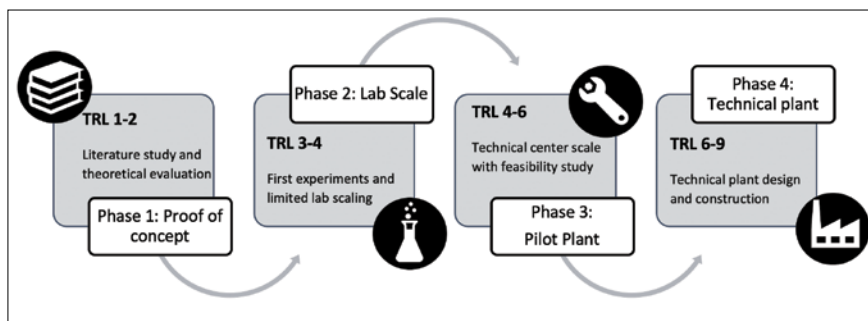


FIGURE 5. Technology readiness levels define the four phases of scaling an electro-organic reaction

ammonium salts must also be considered from a process engineering and economic perspective. These chemicals are not only expensive, but are also often toxic. Therefore, a recycling process must be implemented when using them.

#### Material stability and impurities.

To ensure safety and prevent contamination in wastewater or products, attention must also be paid to the long-term stability of materials, such as electrodes. Electrode materials should also be carefully chosen to avoid toxic metals and contamination. A certain amount of instability must be expected, therefore toxic metals, such as mercury, lead or cadmium, are to be avoided. To design an economical process, long-term stability tests for materials like electrodes, sealings and membranes are crucial prior to scaling up. Membranes should be tested for at least 1,000 hours, with a focus on their stability towards organic media. The availability of robust membranes in the market is limited, so it is important to consider material stability and availability early on, especially in organic electrochemistry.

Laboratory-scale experiments often use high-grade chemicals, but in pilot- or industrial-scale plants, lower-purity grades are used. This can lead to issues not observed in the laboratory, such as particle blockages or damage of coated electrodes. Contamination can also result in gas emissions that need to be quenched to provide safety.

#### Process systems and economics.

In addition to differences in the chemicals used and the stability of the materials employed, the general availability of pilot systems must also be considered. Electrochemical process systems require highly custom-

ized designs, making standardized package units impractical. This results in a complex and costly scaling process, even on pilot-plant scales. Developing custom concepts with manufacturers can slow down or prevent piloting. To ensure a smooth scaling process, it is important to consider pilot system design early on. For example, persulfate electrolysis requires individually developed and optimized cell types and electrode materials, with more than five unique installations worldwide. To establish electrochemistry as a competitive technology, economic competitiveness with optimized standard processes is crucial.

In addition to comparing operating costs (OPEX), carbon emission costs must also be considered. Long-term stability tests for electrode materials and membranes are important to control irregular operational costs. Regional differences in the cost of base chemicals, such as caustic soda, and restrictive wastewater guidelines can also affect economic efficiency.

Downstream processing and simplifying organic synthesis steps are also important factors to consider. Chemical parameters and environmental influences are not the only decisive factors in the industrial environment. One of the most important factors is the scalability and technical feasibility of processes. There are different examples of electrochemical processes that have been implemented on an industrial scale in the chemical industry. The production of Lysmeral by BASF is an example of organic electrochemistry on an industrial scale with about several tens of thousands of tons per year, in addition to chlor-alkali electrolysis [14].

## Scaling up: step-by-step guide

This section illustrates the process of going from an initial idea to the development of a commercial process. Starting a proof of concept on a laboratory scale will likely result in a small scaleup with laboratory utensils (Figure 3). The next step is a mini plant or pilot-scale plant requiring a technical center (Figure 4). In this step, the scalability of the process is investigated and the influences of larger cells and requirements are unmasked. An industrial-scale plant is the last step of scaleup. The plant will be designed for the desired process, with larger equipment and numbering-up of electrochemical cells.

#### Technology readiness levels.

Today, the process development steps are often expressed by technology readiness levels (TRLs). This is a scale for assessing the state of development of new technologies on the basis of a systematic analysis. On a scale of 1 to 9, it indicates how advanced a technology is. In Figure 5, the four phases of process development from feasibility to technical installation are depicted. The TRLs and the decisive properties of the phases are shown.

But how do you move from the current level into the next phase? When do you take the step out of the laboratory? What are the most crucial parameters to consider in each step? To answer these questions, you must first determine what you want to achieve in each of the scaling steps.

**TRL 1–4.** In the TRL 1–2 phase, a theoretical proof of concept is executed. Typically, you perform a literature study to represent the current state of the art and consider the feasibility of your idea. After the theoretical study, the next step includes performing experiments and evaluating the feasibility of the chemistry behind your idea. After proving the chemical viability and therefore reaching a TRL of 3–4, the next step is scaling.

**Beyond TRL 4.** To take the step toward a demonstration facility and thus prove the industrial feasibility, some parameters must first be precisely evaluated before reaching a

## CHECKLIST FOR SCALEUP

- ✓ Safety
- ✓ Long-term stability
- ✓ Tests with original chemicals
- ✓ Supplier
- ✓ Economic feasibility
- Are your parameters scalable?

TRL up to 6. The parameters mentioned in the earlier section, such as safety, long-term stability, chemical purity, supply source and economic viability for the process should be discussed. As part of the safety assessment, any potentially released gases should be examined and a plan must be developed for handling them. In addition, the scalability of the chemicals used in organic electrochemistry should be considered with regard to safety. Furthermore, the organic reaction should have been sufficiently studied so that any undesired reactions are known.

In the scaled-up process, the long-term stability of the selected materials is also an important safety consideration. In the laboratory, stable materials should have been identified for all components, such as pumps, hoses, seals, and similar items. In terms of scaling up, the same qualities of chemicals used in the pilot-scale should have been used in the laboratory. This results in circumventing unplanned events such as instabilities and leakage from the outset.

**Suppliers.** Once everything is ready to start scaling up, the search for suppliers starts. A pilot plant is often like a tailor-made suit that is precisely designed for the organic electrochemical reaction. It is important to pay attention to the commercial availability of materials, such as solvents, electrode materials, seals and more, and to clarify the question of in-house or outsourced engineering. Besides process and chemical parameters, the economic efficiency is decisive for scaleup.

**Data generation.** If the pilot plant phase is successful and you are able to transfer a laboratory reaction into a technical center, you have to start generating resilient data. These data will be the basis for calculations of operational and capital expenditures costs. Last but not

least, you have to decide whether your process is not only chemically feasible, but also suitable for industrial implementation. ■

*Edited by Dorothy Lozowski*

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## Conducting Hazard Reviews: A Practical Guide to Implementing Impactful Process Hazard Analyses

The insights reported here will help guide and encourage engineers in facilitating high-quality and effective hazard analyses in their facilities

**Bill Timbers**

Timbers Consulting

**U**ndertaking and completing a well-planned hazard review might just be the best thing you ever do on a single day at work, or in your entire career. It could also very well be an easy task to undertake, or at least to think about and initiate. Initiating and completing a well-thought-out plan for your hazard review can also allow you to create maximum value for your company, colleagues, community and industry — and be a literal lifesaver at the same time (Figure 1).

Creating a hazard review will not necessarily be easy every time, and can involve a number of conflicts and challenges, some completely unexpected. Learning how to use, deploy and conduct effective hazard reviews can also help you become a booster and mentor for others on their journey to excellence in hazard review and analysis. In addition to operational excellence, economic value will come with improved process performance, reduced downtime and associated costs, as well as an improved morale for all team members, who can be proud of their organization.

### Why do a hazard review?

A question often heard in the past was “Why do I have to do a hazard review? Isn’t this the job of the safety department?” Or perhaps, “I’m a process engineer (or a manager) and I’m way too busy with real work to do this type of activity, give it to someone else who is not as busy!” Or another that is especially painful to hear after an event has just occurred: “I’ve worked here for 10, 20, 30 or 40 years and this has



**FIGURE 1.** Crafting an effective hazard review will require foresight and initiative to make sure all necessary steps are executed properly

never happened before...”

Do these questions all sound familiar? Hopefully they are not as common as they once were in the chemical processing industries, but unfortunately this attitude still arises from time to time, especially on schedule-driven projects that are over budget and involve specific safety and environmental concerns.

### What exactly is a hazard review?

A hazard review, and its subsequent analysis, are among the many methods used to assess risk. The process entails describing a system, or a component of the system that involves, or is related to, an activity that could occur within the organization. During the performance of the activity under review or consideration, an event may be encountered that could cause or contribute to the occurrence of an adverse consequence to one, more or all risk receptors, such as safety, the environment, reputation or economic value.

Specifically, a hazard review is the

process undertaken to identify, assess and control workplace hazards and the risks to worker health and safety, as well as impacts on other receptors. Most Authorities Having Jurisdiction (AHJ) in North America require employers to establish an occupational health and safety program in their workplace. A hazard review and assessment process is an essential part of an organization’s safety culture and the underlying safety management system. Ensuring that an effective hazard review and assessment system is in place and functioning efficiently goes a long way toward minimizing risks to both employees in the workplace, as well as stakeholders and members of the community. An effective hazard review and assessment program also helps to confirm compliance with safety regulations that are needed to create and maintain a safe work environment for all involved personnel, both company employees and those from partner organizations like suppliers and customers.



**FIGURE 2.** There are a number of resources that can be used to analyze possible hazard scenarios, including safety datasheets and equipment operating manuals

### Basic outline of a hazard review

Hazard or risk analysis involves a structured process used to identify both the extent and likelihood of consequences associated with hazards that may be present. To fully analyze the hazards associated with a scenario at your site and provide an effective analysis to allow risk mitigation, you need to take into account several fundamental concepts, described in the following sections, in the absence of other safeguarding procedures.

Another caveat that the team will need to consider is the fact that most systems never truly eliminate a hazard or a risk unless a redesign is undertaken, the risk is transferred elsewhere, or the activity is never undertaken or permanently stopped. Otherwise, mitigation can only be done by implementing safeguards to minimize or significantly reduce the frequency of occurrence of an adverse event.

For example, consider the manufacture of paint products from flammable hydrocarbons that can potentially explode or cause a fire. In this case, nothing can be done within the existing process to fully eliminate a fire or explosion hazard risk, unless you were to change the manufacture over to a completely different paint formulation. This would eliminate the risk of explosion, replacing it with other, less severe risks that would then have to be reviewed and mitigated by other means and methods.

**Step 1 — Recognition of a scenario, or “knowing that you don’t know.”** Where do you start? You

may have been lucky, and have never had an accident before at your site — or so you’ve been told. Or, you’re a new employee and you’ve been asked to undertake a hazard review, for example, related to the use of natural gas within a process to fire a burner using a compressed-gas cylinder.

Start by recognizing that you “know that you don’t know” and work toward knowing all you can. This includes gaining knowledge of the work process for completing a hazard review and analysis, and the specific task at hand, which in this case, would be the safe and effective use of compressed-gas cylinders inside a building to fire a burner system. To best accomplish this task, the following tasks are recommended:

- Do a “walk-around” using the appropriate personal protective equipment (PPE) assigned to you. Observe the area where the gas cylinder will be used and complete a sketch of the area to familiarize yourself with the layout and any facility siting concerns
- Ask fellow employees or other people in the area about what issues could arise by installing or using a natural-gas fired burner
- Inquire about any other related past incidents at the site, either within the company itself or the industry in general
- Research potential related issues in the public domain
- Assemble a reference package of all key process safety information (PSI), including (but not limited to) the following:

- Safety datasheets (SDS) for the natural gas (methane) that will be contained in the cylinder
- Burner and cylinder details from the original equipment manufacturer (OEM)
- Information on gas detection systems, either installed or portable, being used on site
- Handling procedures for compressed-gas cylinders
- Building and workspace access and egress routes, for both normal routing and under emergency conditions
- Confirmation of who normally works in the area and for what period of time to establish whether or not the area is considered to be an “occupied space” or not. One key factor that clearly establishes 100% occupancy is if there is a meeting room in the immediate area that anyone can book at any time of the day, or a training room, lunchroom or an office with a person’s name assigned to it, who works day or night shifts in a role that is covered over the entire year

**Step 2 — What could go wrong in the absence of safeguards?** Work with a colleague, especially someone who will be in the workspace and possibly will be responsible for receiving, using and handling the natural-gas cylinder, as well as operating the burner system, to generate a list of possible scenarios that should be considered in a hazard review and analysis. Refer to the SDS for methane, the burner and cylinder operating manuals and any relevant OEM brochures to get a comprehensive list of scenarios and safeguarding to be used or present (Figure 2). Factors to consider include the following:

- Receipt and movement of gas cylinders
- Primary valve break on the high-pressure natural-gas cylinder
- Loss of primary containment (LOPC) of the natural gas into the facility, considering the below cases:
  - No ignition case, no gas odorant present, people present
  - No ignition case, gas odorant

present, people present

- o Delayed ignition case, people may be present
- o Immediate ignition gas, people may be present

**Step 3 — How likely is it to occur in the absence of safeguarding?** If in doubt, “go big or go home” and assume an occurrence of an event taking place anywhere from once per year to about once every 10 years. For the compressed-gas cylinder example, we will assume a leak from a faulty gas-cylinder valve connection with people present and absolutely no safeguarding in place. Note, the proviso of “in the absence of administrative and engineering safeguards” is a requirement for a number of best practices, such as those required by the U.S. Dept. of Labor’s standard, OSHA CFR 29 1910.119 — Process Safety Management of Highly Hazardous Chemicals, and is used so that safeguards are not credited more than once, and that the focus is on the worst case, not the most likely, less harmful case. This legislation contains requirements for preventing or minimizing the consequences of catastrophic releases of toxic, reactive, flammable or explosive chemicals. These releases may result in toxic, fire or explosion hazards.

Should an LOPC occur with people present, and there is no gas detector available, no odorant in use and no ventilation, then as according to the SDS, without ignition, the released methane could displace the air in the room and the oxygen concentration could be reduced below 19.5 vol. %, compared to a normal concentration of about 21 vol. %, which could then result in the asphyxiation of any and all people present during the time of the release.

**Step 4 — What are the consequences that could occur for all risk receptors?** These consequences may include adverse impact on people (loss of life, injury or illness), the environment (harm to air, water and soil, both on and off the physical site) and finances (damage to property or assets, loss of revenue or negative reputational impact). Some potential risk outcomes are listed below for the compressed-gas cylinder hazard

scenario:

- Asphyxiation — Fatalities and equipment damage, as well as production outages and potential environmental release
- Flash fire — Fatalities or burns and equipment damage
- Explosion — Fatalities and equipment damage
- Jet fire — Fatalities or burns and equipment damage

**Step 5 — What is the level of risk in the absence of safeguards?**

Note, to confirm all of the below considerations for the risk receptors, it is necessary to fully develop an approved corporate risk assessment matrix (RAM).

- Safety — High, unacceptable without safeguards
- Environment — Low, unacceptable without Safeguards, regardless of the risk
- Economics — Medium, unacceptable without safeguards, regardless of the risk
- Reputational risk — Cannot be developed without corporate guidance via an approved RAM.

**Step 6 — What can you do to eliminate or mitigate the harm and reduce the level of risk?**

Below are some recommended practices to address the hazard and risk associated with the compressed-gas-cylinder scenario.

- Develop operating and maintenance procedures, complete with training
- Use gas only with odorant
- Move any burn to an inherently safe location, like outside of the building
- Control access to the area
- Employ gas detection and appropriate heating, ventilation and air conditioning (HVAC) systems
- Explore the potential use of non-fired equipment
- Specify flame-resistant PPE
- Check for leaks and pressure-test all equipment prior to use
- Explore the use of a burner management system (BMS)

**Step 7 — How much will it cost to achieve significant and realistic safeguarding?** This cost should look at not only financial resources, but also employee time and effort, to determine if the cost will be proportional or disproportional to the reduced level of risk. For example, if it will cost

\$1 million to mitigate a risk that is only costing \$10,000, is this recommendation a valid one for the organization to undertake? Or, alternatively, if the mitigation requires a number of team meetings and expenses to design, acquire, install and maintain, and the likelihood and the consequences do not change, is the of value to your organization to adopt even more work of low, or questionable value? Below are some specific questions to consider.

- How much will it cost to reduce your risk from High/Unacceptable to Medium/Acceptable with safeguards, or even to Low Risk?
- Will the costs to achieve an acceptable level of risk be within budget? If so, and management approves and supports your review, then you can begin establishing an “As Low as Reasonably Practicable” (ALARP) assessment on your hazard reviews and analysis procedures. ■

*Edited by Mary Page Bailey*

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## A Look Back on 80 years of Thin-Film Evaporation

By: Christian Eickhoff, Buss-SMS-Canzler GmbH

Eighty years ago, in 1944, Dr. Hans Müller from Winterthur, Switzerland filed a patent application for a device designed to process liquid substances at the Swiss Federal Institute of Intellectual Property in Bern. Liquids prone to fouling on heated surfaces, as well as thermally sensitive or viscous substances, have always presented significant challenges in thermal processing.

Müller's original patent describes the thin-film evaporator as follows:

*"...A device for processing liquid substances, characterized by a vertical heated cylinder and an internal stirrer that distributes the liquid along the inner wall of the treatment zone, moving it along the heating surface with rigid blades mounted on a rotor."*

The patent for a vertical cylindrical thin-film evaporator with a rigid-blade rotor was granted in 1947. Recognizing its immense potential, Luwa AG, based in Zürich, acquired the patent. Subsequently, a pilot plant was established in Zürich, and the first machines were manufactured in Muri, Switzerland. To this day, this type of thin-film evaporator is globally recognized under the name LUWA evaporator.

In 1919, Richard Samesreuther founded Samesreuther & Co. GmbH in Butzbach, Hesse, Germany. Initially, the company specialized in repairing or manufacturing locomotive fireboxes using a patented copper-welding process. Later, it expanded into producing apparatus for high operating pressures from special materials for the chemical manufacturing industry. These included the company's patented Samka ranges of full- and half-pipe heating coils and dimple jackets.

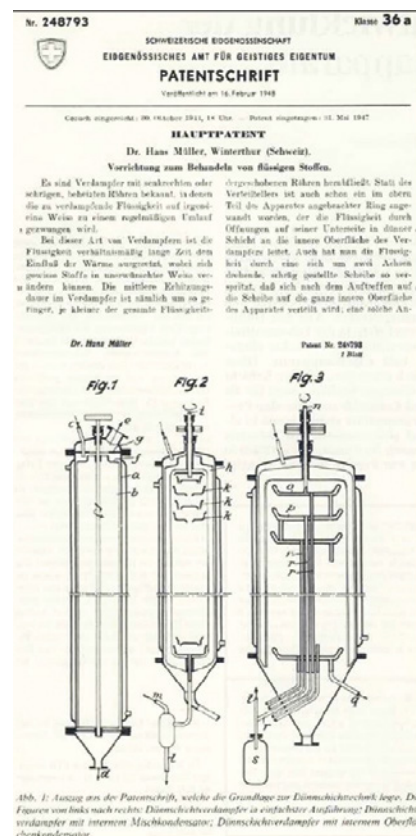
In 1952, Samesreuther & Co. GmbH signed a contract with Farbenfabriken Bayer AG to manufacture and distribute a vertical cylindrical thin-film evaporator with movable metallic wiper blades, known as the Sambay evaporator.

A third type of thin-film evaporator was introduced in 1957 by Carl Canzler KG in Düren, Germany. This design employed a rotor with movable graphite wiper blades and was used in both thin-film and short-path evaporators. Carl Canzler KG acquired a license for this design from Arthur Smith of Rochester, N.Y., and marketed it under the name Rotafilm with Smith Rotor.

In 1964, Samesreuther & Co. GmbH became Samesreuther Müller Schuss GmbH (SMS), leading to the formation of Luwa-SMS GmbH in 1972. Since then, LUWA evaporators have been produced alongside Sambay evaporators at the Butzbach facility. Following the acquisition by Buss AG in 1983, the company was renamed Buss-SMS GmbH Verfahrenstechnik, and the current name, Buss-SMS-Canzler GmbH, was adopted after the merger with Canzler GmbH in Düren in 2003.

Building on the foundation of these vertical, cylindrical thin-film evaporators, numerous additional machines for the thermal treatment of mixtures that are difficult to handle (due to heat sensitivity or extreme viscosity, for example) have been developed. All of these machines operate on the same basic principle: processing a continuously flowing thin film of product, influenced mechanically, with short residence time and indirect heat transfer. These include vertical and horizontal conical thin-film evaporators, short-path evaporators, thin-film evaporators for highly viscous materials, and vertical and horizontal thin-film dryers.

Thin-film evaporation technology has continued to advance over the past 80 years. Additionally, modern capabilities in process and mechanical engineering — including computational fluid dynamics (CFD), discrete-element and finite-element methods, and process simulation software — as well as more precise and efficient manufacturing techniques for various materials,



**FIGURE 1.** The original patent for thin-film evaporation technology was filed in Switzerland in 1944. The technology is now widely used in industrial separations, including distillation, concentration, stripping, deodorizing, degassing and more (Image courtesy of Buss-SMS-Canzler GmbH)

enable the development of optimal, customized solutions for nearly any specific application.

Drawing on over 13,000 documented trials conducted at former laboratories and pilot plants in Zürich, Butzbach, Düren and the current facility in Pratteln, Buss-SMS-Canzler GmbH has designed and manufactured nearly 7,000 rotating thermal-separation machines.

*Edited by Mary Page Bailey*

### Further reading

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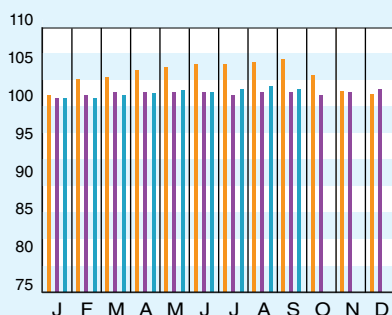
# Economic Indicators

Download the CEPCI two weeks sooner at [www.chemengonline.com/pci](http://www.chemengonline.com/pci)

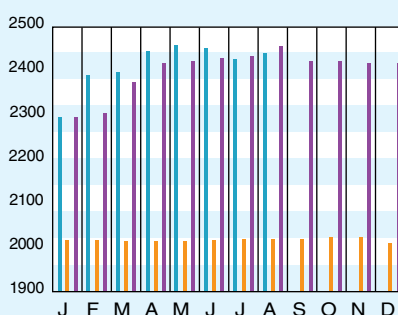
CURRENT BUSINESS INDICATORS	LATEST	PREVIOUS	YEAR AGO
CPI output index (2017 = 100)	Sept. '24 = 101.0	Aug. '24 = 100.8	Jul. '24 = 100.8
CPI value of output, \$ billions	Aug. '24 = 2,417.9	Jul. '24 = 2,433.4	Jun. '24 = 2,417.9
CPI operating rate, %	Sept. '24 = 77.4	Aug. '24 = 77.3	Jul. '24 = 77.5
Producer prices, industrial chemicals (1982 = 100)	Sept. '24 = 306.5	Aug. '24 = 310.8	Jul. '24 = 311.3
Industrial Production in Manufacturing (2017=100)*	Sept. '24 = 99.1	Aug. '24 = 99.5	Jul. '24 = 99.0
Hourly earnings index, chemical & allied products (1992 = 100)	Aug. '24 = 230.3	Jul. '24 = 229.1	Jun. '24 = 228.7
Productivity index, chemicals & allied products (1992 = 100)	Sept. '24 = 94.7	Aug. '24 = 95.5	Jul. '24 = 94.1
			Sept. '23 = 100.5
			Aug. '23 = 2,428.0
			Sept. '23 = 78.6
			Sept. '23 = 309.4
			Sept. '23 = 99.6
			Aug. '23 = 224.3
			Sept. '23 = 93.6

2022 2023 2024

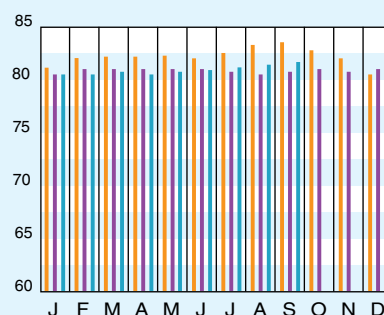
**CPI OUTPUT INDEX (2017 = 100)<sup>†</sup>**



**CPI OUTPUT VALUE (\$ BILLIONS)**



**CPI OPERATING RATE (%)**



\*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.

<sup>†</sup>For the current month's CPI output index values, the base year was changed from 2012 to 2017

Current business indicators provided by S&P Global Market Intelligence, New York, N.Y.